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OF
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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O.K.

The professional papers contained in The Journal are published prior to the meetings at which they are to be presented, in order to afford members an opportunity to prepare any discussion which they may wish to present.

The Society as a body is not responsible for the statements of facts or opinions advanced in papers or discussions. C55

THE JOURNAL

OF

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

VOL. 33 FEBRUARY 1911 NUMBER 2

MEETINGS OF THE SOCIETY

MEETING OF THE SOCIETY IN NEW YORK FEBRUARY 14

At the February meeting of the Society in New York, the subject will be the Mechanical Engineer and the Prevention of Accidents, on which a paper by John Calder of Ilion, N. Y., will be presented by the author. Invitations have been extended to the members of the Industrial Safety Association and the Committee on Industrial Accidents of The National Civic Federation; and arrangements have been made to open to visitors both before and after the meeting the American Museum of Safety, located in the Engineering Societies Building. Discussion is expected from representatives of these organizations and from engineers, manufacturers and others interested in the problem of the prevention of industrial accidents.

MEETING OF THE SOCIETY IN BOSTON, FEBRUARY 17

A meeting of the Boston Section of the American Institute of Electrical Engineers, with the coöperation of The American Society of Mechanical Engineers and the Boston Society of Civil Engineers, will be held on Friday evening, February 17, 1911, in that city. R. A. Philip of the Stone and Webster Engineering Corporation, an associate member of the American Institute of Electrical Engineers, will present a paper on certain phases of the general subject of economic limitations to aggregation of power systems. This paper was suggested by the discussion on Smoke Abatement at the meeting of November, when Dwight T. Randall, Mem.Am.Soc.M.E.

presented it as his view that control of the smoke nuisance could be brought about only by the centralization of coal-burning plants in large units and the elimination of miscellaneous coal burners. The paper by Mr. Philip elaborates this statement.

MEETING OF THE SOCIETY IN NEW YORK, JANUARY 10

At the meeting of the Society in New York, January 10, a paper was read upon the Mechanical Handling of Freight, by Samuel B. Fowler, Consulting Engineer, of Boston, which had previously been presented at a monthly meeting in Boston. The author emphasized the fact that the object in improved terminal facilities is not wholly the reduction in the cost of handling goods, but to a large extent it is to reduce the total transportation cost and to permit a material gain in income from this source and a decrease in rates. The paper was discussed by Lincoln DeGroot Moss, W. B. Waterman, Chas. T. Barney, Spencer Miller, J. H. Norris, S. B. Paine and G. H. Condict. Mr. Condict showed a large number of lantern slides illustrating conditions at terminals in this country and abroad, where there were no mechanical facilities for handling freight, and in contrast to these conditions at certain terminals abroad where modern equipment had been installed.

MEETING OF THE SOCIETY IN PHILADELPHIA, JANUARY 28

A meeting of the members of the Society resident in and near Philadelphia has been called for January 28, 1911, in the Engineers Club of Philadelphia, to discuss the holding of meetings of the Society in that city, on the plan of those already in progress in New York, Boston, St. Louis and San Francisco.

At a preliminary meeting on December 30, at which about thirty of the members were present, a committee, composed of Thos. C. McBride, Chairman, D. R. Yarnall, Secretary, A. C. Jackson, J. E. Gibson, W. C. Kerr, J. C. Parker and James Christie, was chosen to communicate with the Engineers Club of Philadelphia and the Franklin Institute with a view to coöperation.

MEETING OF THE SOCIETY IN BOSTON, JANUARY 31

The January meeting of the Society in Boston with the Boston Section of the American Institute of Electrical Engineers and the Boston Society of Civil Engineers, which will take the form of a dinner

similar to that given a year ago, is announced for January 31 in the Hotel Somerset. Prof. Elihu Thomson, Mem.A.I.E.E., of Lynn., Mass., will be the guest of honor; and official representatives of the three national societies are expected to be present, as well as engineers from New York and elsewhere, many of them representing other societies and scientific or educational institutions. Prof. Arthur E. Kennelly, Mem.A.I.E.E., of Harvard University will act as toastmaster. The dinner last year was attended by over 400 guests and there is every reason to suppose that this event will equal if not surpass the former occasion.

STUDENT BRANCHES

The Armour Institute Student Branch held its regular meeting on January 4, when Charles E. Sargent, Mem.Am.Soc.M.E., read a paper on Gas Engines illustrated by photographs of various engines and engine parts.

At a meeting of the Columbia Student Branch on December 19, A. S. Mann, Mem.Am.Soc.M.E. was the lecturer. He outlined the career of the technical graduate in a large plant, showing that a young man need not be afraid to begin at the bottom, and pointed out the chief cause of failure, the lack of application of knowledge to the solution of practical problems. On January 7, Carlos de Zafra described in a lecture before the Branch the manipulation of large guns, mortars, torpedos and mines. This was illustrated by lantern slides and moving pictures in which the discharging of torpedos and the diving and running of a submarine were shown.

At the November 19 meeting of the Kansas University Student Branch Professor Shaad delivered an address on the Electrification of Steam Railways, which was followed by a general discussion. On December 2, George W. Russell read a paper on Furnaces and Grates; and Prof. Perley F. Walker, Mem.Am.Soc.M.E., presented a paper on Power Plants. At the meeting on December 14, Mr. Phillips gave an address on Induction Motors, which was followed by a general discussion. The second annual meeting was held on January 5, and lasted all day, followed by a dinner in the evening. The professional program included the following papers: Some Recent Improvements in Locomotive Boiler Construction, by William J. Lighty; Results of a Seven-Hour Test on an Air-Lift Pumping Outfit, by John D. Farrell and Thomas A. Purton; An Electric Railway Test, by W. C. McBain, Mem.Am.Soc.M.E., and the Results of a Two-Hour

Test of a 1100-h.p. Gas Engine, by Wilbur H. Judy. Prof. H. Wade Hibbard, Mem.Am.Soc.M.E., delivered an illustrated address on Scientific Management, and Capt. DeF. Chandler, U. S. A., a talk on Aeronautics, amplified by lantern views.

At a meeting of the Stanford University Mechanical Engineering Association on December 14, the following officers were elected for the ensuing semester: H. H. Blee, president, C. H. Benson, vice-president, and E. L. Ford, secretary and treasurer. After the election Prof. W. R. Eckart, Mem.Am.Soc.M.E., gave an illustrated talk on the Modern Irrigation System in Egypt.

The University of Arkansas has held regular meetings on every second and fourth Monday nights since the beginning of the college year. At the meeting on December 19, John Baxendols read a paper on the Design of Heating Plants for Houses relative to the Humidity of the Air, which was followed by a general discussion. Prof. B. R. Wilson, Mem.Am.Soc.M.E., read a paper on Cement and its Uses. This was discussed by Dr. Brough.

At the meeting of the Stevens Engineering Society held on January 6, George P. Ward delivered a paper on the Generation of Steam Power, illustrated by lantern slides. This paper was discussed by Messrs. Blythe, Schroder, Barton and Clouser.

On January 6 the University of Illinois Student Branch held its election. The following are the new officers: F. J. Schlink, president; H. H. Constant, vice-president; E. J. Hasselquist, secretary; and P. A. Faust, treasurer. Following the election, G. W. Philleo discussed the paper by S. L. Napthaly on a Test of a 10,000-kw. Turbine.

MEETING OF THE COUNCIL

A meeting of the Council was held, January 10, 1911, in the rooms of the Society, the President, E. D. Meier, presiding. There were present: Messrs. Brill, Crawford, Herr, Flagg, Gantt, Hartness, Hunt, Hutton, Katte, Moultrop, Reist, Smith, Sando, Vaughan and the Secretary. Regrets were received from Messrs. Humphreys and Goss.

Voted: That the following telegram be sent to Rear-Admiral Melville, Past-President and Honorary Member: Council Mechanical Engineers in session today sends congratulations to its Honorary Member and Past-President on his birthday and wishes him many years of health, activity and usefulness.

The minutes of the meeting of December 9, 1910, were read and approved.

The following deaths were announced: W. L. Pierce, R. B. Talcott, Gus. C. Henning.

The President announced the following appointments: Finance Committee: W. L. Saunders, H. L. Doherty; Library Committee; W. M. McFarland, E. G. Spilsbury; Meetings Committee: C. J. H. Woodbury; Membership Committee: W. H. Boehm; Research Committee; R. C. Carpenter; Publication Committee: Chas. I. Earll; Committee on Resolutions to Institution of Mechanical Engineers: W. F. M. Goss, Chairman, Chas. Whiting Baker and E. D. Meier; House Committee: S. D. Collett; Tellers of Ballot for officers and members: W. T. Donnelly, Geo. A. Orrok, Theodore Stebbins.

The Secretary announced the result of ballot for an Excutive Committee of the Council and that the Committee had met and organized as follows: President E. D. Meier, Chairman, Alex. C. Humphreys, Vice-Chairman, Chas. Whiting Baker, F. R. Hutton, H. L. Gantt, Jesse M. Smith.

Voted: To approve the recommendation of the Executive Committee and to appoint the following Committee on a Code of Ethics: Chas. Wallace Hunt, W. F. M. Goss, John E. Sweet, such Committee to report to Council.

Voted: To approve the application for Student Branch at the State University of Kentucky, Lexington, Ky., and Ohio State University, Columbus, Ohio.

Whereas: A communication has been received from the members of the Society in San Francisco proposing that the Spring Convention of 1915 he held in that city.

Voted: That the invitation be acknowledged with thanks but for reasons of weight decision be deferred.

Voted: To refer to the Executive Committee with power the selection of time and place for the Spring Meeting.

Voted: The following resignations were accepted: C. B. Allen, G. W. Rowel, S. Howard-Smith, St. George H. Cooke, E. Schlemmer, Jr. F. L. Norton, R. B. Hartness, P. C. Morrow, W. S. Morehouse, James M. Cremor, W. D. Forbes, C. W. Boyer, C. J. Julstedt, J. McGeorge, A. S. Vogt, W. O. Webber and E. W. Roberts.

Voted: The following were deemed to have declined election: Chas. R. Ammermann, M. G. Farrell, Wm. H. Hazard, John Orr, Chas. N. Underwood, Evans Ward, L. E. Zatlin, Frank Burgess, T. D. Casserly, H. N. Davock, R. Emerson, Edwin S. Hallett, Wm. H. Lines, B. S. Nelson, D. D. Rowlands, Edson M. Stevens, Jas. L. Wick.

The Secretary read a communication from James M. Dodge, Past-

President, presenting to the Society an autograph letter of James Watt together with an engraving of a picture of Watt by Sir William Beechy, R. A.

Voted: That the Council accept the gift and extend a vote of thanks to Mr. Dodge.

Voted: That the matter of raising the remainder of the share of The American Society of Mechanical Engineers on the mortgage on the property of the Engineering Societies, be referred to a special committee consisting of Chas. Wallace Hunt, Past-President, the Chairman of the Finance Committee, and one other to be selected.

SEVENTIETH BIRTHDAY OF ADMIRAL MELVILLE

On December 31, the attention of a few friends of Rear Admiral Geo. W. Melville, Hon.Mem.Am.Soc.M.E., was called to the fact that

on January 10 he would be seventy years old. The suggestion was made that as many of his friends as possible be notified so that

they could write him letters of congratulation. But upon further consideration even this seemed too modest and simple a method of celebrating this event. The more they thought of it the more the stature of the man and his achievements grew. On January 2 a committee of five was formed who communicated with a hundred

1841
1911
Rear Admiral
George Wallace Melville,
Engineer in Chief U. S. Navy
(Retired)
Seventieth Meridian of Your Life's Journey.
Your Success
the natural result of keen insight, clear reasoning, devotion to duty, undaunted truth and courage which carved pathways through arctic ice and made vibrant with life the very metal of your engines.
American Engineer.

of his friends suggesting the presentation of a substantial memorial. So prompt and warm were the responses that the preparations were at once made and on the morning of January 10, Walter M. McFarland and A. M. Mattice, on behalf of the committee, went to Philadelphia and presented the Admiral with a beautiful silver platter

of admirable workmanship and a memorial resolution handsomely engrossed. These are here reproduced from photographs. In thus honoring a great engineer, the profession did honor to itself.

JAMES WATT LETTER

Through the courtesy of the Crosby Steam Gage and Valve Company who are issuing a James Watt Souvenir, we are enabled to give the wording of the letter written by James Watt and presented to the Society by George Tangye, Esq., at the meeting in Birmingham in July last:

Birmingham, May 10th, 1777.

Dear Sir:

Yours of the 8th before me. Salmons man is making wheel engine boiler and seems to do tolerably well.

I am astonished how Joseph deceived himself and us in his effect of Bow boiler. I have not seen him since—but I remember he told me that there was a prodigious odds in the quality of some of their coals by others. Did you say whether pushing in the damper to a certain degree did not produce a better or as good an effect as opening the hole in chimney—and was you absolutely certain that no feed got into the boiler during time of experiment.

I think that you are in a good train at Shadwell and recollect no more cautions on that head.

I have made the best apology I could to Mrs. B. though she talks the words of wrath; she is in very good humour and all are well.

When I see the table I can reason upon copper boylers.

I saw the Battering Ram, or devil incarnate, go today above 60 strokes per minute and work its own regulators. All the stampers were assembled. They thanked God that Webb could not make feaders in. He told them he had one of these and in hand. Moore wants a score of large ones for his own use. The story is all over Birmingham and I expect we shall have customers by the dozen. I imagine that they may be made to work forges and tilts fast enough for any purpose.

Cleobury Iron has turned out dammed bad, the piston rod for Huel bussey was very well forged by Dixon and upon heating it to float it fell in two at the shooting and Joss rejoiced in his heart thereat, but not Joss nor Joseph could weld it again—nor would it weld to any other iron by no trick.

Dixon is fagotting one out of Sweedish small bars.

The branch of Battering Rams may turn out very cursedly, as I dare say nobody will attempt them with common engines, and I don't know if they could be made to do. I have invented an admirable thing for opening the regulator which acts by a spring and does it quicker than thought. All Webb's fears are that when a larger one goes at the rate that his does, that no body will come near it.

It has demolished all the fixtures many times already, and I suppose must be wholly made of cast iron.

Dangerfield has been here and sett Joss to growling and drinking for two days this week.

I should make myself easy about profits, if any were coming in at all, but a total stagnation as has been hitherto cannot do at all. I am clear that you should make your bargain sure before you leave London and lett us know what we are to gett with some probably, at least.

As to the Cornish affair. It has also struck me that I should go first and that something should be done before you come.

Adieu.

I wish you a clear head and a firm heart on Tuesday. Pray weigh the coals and observe the quality. Keep well with Rothwell. I think he deserves it.

Yours,

J. WATT.

HONORARY MEMBERS OF THE ENGINEERS CLUB

At a meeting of the Engineers Club of New York on January 11. 1911, Rear-Admiral George W. Melville, Hon.Mem.Am.Soc.M.E., and Thomas Alva Edison, Hon.Mem.Am.Soc.M.E., were made honorary members of that organization.

NECROLOGY

GUSTAVUS C. HENNING

Gustavus Charles Henning, one of the foremost experts in the testing of steel and an inventor of testing apparatus, died at his home in New York City on December 30, 1910.

Mr. Henning was born in Brooklyn in 1855, and educated at the Brooklyn Polytechnic Institute. In 1876 he was graduated from Stevens Institute of Technology where during his college course he was fortunate enough to come under the influence of Prof. Robert H. Thurston.

Immediately after graduation he entered upon the work of inspection of steel for engineering structures. This work brought him in touch with the late George S. Morison and made him familiar with the problems of structural material.

His inventive genius and the opportunities for its exercise resulted in the design of a form of extensometer which he described in two papers before the Society, A Mirror Extensometer and A Roller Extensometer. His study of the defects and limitations of the high-powered testing machines operated on the usual hydraulic principle resulted in his design of a testing machine for full size specimens in which the stretch of the adjusting screws is the measure of the stresses upon the test specimen. The two screws, or more, should be fitted with micrometer extensometers and their uniform stretch within the elastic limit of the material would be a constant measure of the effort without the interference from friction inertia and other causes.

Mr. Henning was a great admirer of the Emery design of testing machines and was sent abroad as a representative of the manufacturers for the installation of certain important British and German orders. Acquaintances which he made during this sojourn resulted in his selection as the official delegate and representative of the Society at certain conferences of the International Society for Testing Materials. It was during this time that Mr. Henning made very important contributions to professional literature in the form of partial reports upon Standardization of Methods of Testing, which will be found in the Transactions, Vols. 6, 11, 12, 14, 17, 18 and 20.

The severity of Mr. Henning's labors at this period caused a breakdown of health from which it is fair to say that he never fully recovered.

On the formation of the American Society for Testing Materials, Mr. Henning found himself rather in the insurgent class as the result of his experiences and opinions formed during his professional work. For this reason he took no part in the formation of the standard specifications and attacked them vigorously when presented before the Society. Business changes and the development of special firms with large capacity for the conduct of the work of inspection of structural material resulted in Mr. Henning's abandonment of professional work in that particular field.

The last years of his life during the continuance of a state of health which warranted his attention to business, were devoted to developing the use of the diamond as a cutting face for tools. He found considerable development for this special work in the manufacture of electrical details in hard rubber. He presented a paper before the Society at a monthly meeting in December 1904, elaborating in some detail his special achievements in this field.

Mr. Henning became a member of this Society in 1880. He was also a member of the International Association for Testing Materials, the Iron and Steel Institute of Great Britain, the Iron and Steel Institute of America, the American Society for the Advancement of Science, the American Geographical Society, and the American Institute of Mining Engineers. His other contributions to the Society were Notes on Steel; On the Elastic Curve and Treatment of Structural Steel; and Investigations of Boiler Explosions.

JAMES D. MACPHERSON

James D. Macpherson was born in Glasgow, Scotland, September 15, 1872. He was educated in the public schools of his native city, and there served his apprenticeship in the machine shop. He later went into the drafting room of Lees and Anderson, builders of marine engines, Glasgow.

After a cruise on a tramp steamer, as assistant engineer, he came to the United States in 1891, entering the service of the James Leffell Company, builders of turbines and water wheels, first in New York and later in their shops at Springfield, Ohio. While there he was employed as assistant in the designs for the great turbine plant of the

Niagara Falls Power Company and other work of similar character, until February 1898. He then entered the employ of the Diesel Motor Company of America as chief draftsman and assistant engineer.

By careful reading and home study he had added much theoretical knowledge to his practical experience, and under the guidance of the chief designer, Arthur J. Frith, he mastered the elements of thermodynamics and of electrical science. During 1901 he was active in perfecting and improving the details of construction of the Diesel motor. In 1902 he was chief designer for Diesel engine work for the American and British Manufacturing Company of Providence, R. I.

From August 1903 until his death he was in the employ of the American Diesel Engine Company, first as assistant, and later as chief engineer.

Mr. Macpherson died at Paterson, N. J., on November 9, 1910. He was a man of sterling integrity and loyalty, a careful and conscientious engineer; and the mechanical success of the American type of Diesel engine is in large measure due to him.

He was a member of the Engineers' Club of St. Louis.

WALTER L. PIERCE

Walter L. Pierce was born at Boston, Mass., June 8, 1855, and was educated at the public schools of Boston and New York. In 1878 he entered the employ of the Lidgerwood Manufacturing Company as a stenographer and acquired his technical training while holding this position from private tutors from Stevens Institute. Mr. Pierce was connected with the Lidgerwood Company for thirty-two years, during twenty-nine of which he acted as its secretary and general manager. He died in New York City, December 10, 1910.

Mr. Pierce was remarkable as an organizer and so perfect was his work that no detail of the great business that grew up under his hand was neglected during his long absences from his desk while seeking health. Besides his connection with the Lidgerwood Manufacturing Company he was treasurer of the Hayward Company and of the Gorton-Lidgerwood Company. He was a member of the Engineers' Club, the Machinery Club, of which he was a director, past-president of the National Metal Trades Association, and an associate member of the Naval Architects and Marine Engineers.

EDGAR PARK COLEMAN

Edgar Park Coleman was born July 12, 1867, at Decatur, Ill., and died November 27, 1910, at Buffalo, N. Y. His early education was obtained in the country schools and in the Rose Polytechnic Institute, Terre Haute, Ind. In 1893 he was graduated from Leland Stanford, Jr. University and two years later from Cornell University with the degree of M.M.E. After leaving Cornell he spent one year in the employ of the Metropolitan West Side Elevated Railroad, Chicago, Ill., and the seven years following at the South Chicago Works of the Illinois Steel Company, making quantitative measurements of steam, water, air and gas; efficiency tests of engines, pumps, gas producers, blowers, etc.; and firing boiler trials of hand, stoker, coal dust and gas. He also originated the design now in use of the Porter-Allen 7500-i.h.p. exhaust valve gear; the 8500-i.h.p. extension release gear for Corliss engines and a steam regulating system for five pairs of independent and two cross-compound engines on a common receiver. In 1905 Mr. Coleman took up his work of steam engineering with the Lackawanna Steel Company, Buffalo, N. Y., in which he was engaged at the time of his death.

He was a member of the American Chemical Society and the Park Club of Buffalo.

ROBERT BARNARD TALCOTT

Robert Barnard Talcott was born at Richmond, Va., December 1, 1863, and educated at the public and private schools of that city and of Washington, D. C., later receiving instruction in mechanical drawing in the evening courses of the Linthieum Institute, Georgetown, D. C.

He started his business career by entering the office of W. H. Tenny and Company, merchant millers, Washington, D. C. In 1882 he became draftsman for the E. D. Dent Company, and in 1884 for the supervising architect of the United States Treasury. From October 1906 to February 1909 he was general manager of the Vacuum Cleaner Company of New York City. With the exception of this period, Mr. Talcott, remained in the heating and ventilating division of the supervising architect's office of the United States Treasury until October 1910, when he was furloughed on account of his health. He was at various times assistant chief engineer in this office, consulting mechanical engineer of the Department of Agricul-

ture in Washington and consulting mechanical engineer in connection with the power plant for the United States Soldiers' Home, Washington, and the Walter Reed United States Army Hospital, Washington. He died December 4, 1910, at Lutherville, Md.

Mr. Talcott became a member of this Society in 1907. He was also a member of the American Society of Heating and Ventilating Engineers and the American Society of Inspectors of Plumbing and Sanitary Engineers.

ENERGY AND PRESSURE DROP IN COMPOUND STEAM ENGINES

By Forrest E. Cardullo

ABSTRACT OF PAPER

It is customary to design multi-stage impulse turbines on the assumption that the entropy of the steam remains constant. The effect of fluid friction is to increase the total heat and the entropy of the steam as it flows through the turbine, and to increase unduly the proportion of the power developed in the later stages. An empirical formula is proposed for estimating the quantity of power developed in each stage of such a turbine. This equation is modified so that by its aid the proper pressure drop in each stage may be determined. A graphical solution of the problem is also developed. The methods outlined are applicable to the solution of problems in turbine design when a temperature-entropy table or a total heat-entropy diagram is used.

ENERGY AND PRESSURE DROP IN COMPOUND STEAM ENGINES

CALCULATIONS OF THE DISTRIBUTION OF ENERGY AND PRESSURE DROP AMONG THE STAGES OF A COMPOUND IMPULSE TURBINE

By Forrest E. Cardullo, Durham, N. H.

Member of the Society

In a paper read before the meeting of the Society of Naval Architects and Marine Engineers in Detroit, June 1909, Prof. C. H. Peabody explains a method of determining the pressure in the steam chests of the several stages of a compound impulse turbine. As a substitute for this method the writer submits the following, suggested largely by the method given in the above mentioned paper, which he believes to be both more simple and more exact in application.

2 The general methods open to the designer for determining the properties of steam during its passage through the turbine are three in number. He may make use of empirical equations giving the relation between the heat content, entropy and temperature or pressure of expanding steam, as was suggested by Dr. Steinmetz.[1] He may make use of Mollier's total heat-entropy diagram which gives the relation between the total heat, entropy, pressure and quality of steam. Or he may make use of a table like that of Professor Peabody giving the relation between the temperature, entropy, total heat, quality and specific volume of steam. The last two methods are both more simple and more accurate than the first one and are to be preferred.

3 Assume that a turbine is to be designed having n stages and that the diameters of the moving elements of each stage are the same.

[1] Proc. Am. Soc. M. E., March 1908.

The American Society of Mechanical Engineers, 29 West 39th Street, New York. All papers are subject to revision.

Then, in order to have the steam issue from each set of nozzles at the same velocity, it is necessary to have the same heat drop in each stage. The heat drop per stage will, of course, be $\frac{1}{n}$ of the total heat drop. Were there no retransformation of work into heat, it would be necessary only to find from an entropy table or diagram the entropy and total heat of the steam as it enters the turbine, and the total heat, at the same entropy, of steam of the terminal pressure, to subtract the second quantity from the first in order to obtain the total heat drop, and then to divide this drop by the number of stages to obtain the heat drop per stage. The pressures in each stage would then be found by subtracting the heat drop per stage n times from the initial heat content and finding from the table or diagram the pressure of steam having the heat content so found, at the given entropy.

4 This method may be illustrated by the following problem, taken from Professor Peabody's paper: Assume that the initial steam pressure is 164.8 lb. per sq. in. and the final pressure is 1.005 lb. per sq. in., that the steam is initially dry and saturated, and that the number of stages is two. From Professor Peabody's table, we find the initial entropy to be 1.56 and the intial heat content to be 1193.3 B.t.u. The heat content of steam of 1.56 entropy at the terminal pressure is 871.1 B.t.u. The difference between the initial and final heat content, or the heat drop, is 322.2 B.t.u. The heat drop per stage is one-half this or 161.1 B.t.u. The heat content of the steam entering the second stage is $1193.3 - 161.1 = 1032.2$ B.t.u. The pressure of steam having this heat content and the entropy 1.56 is 18.4 lb., which would be the absolute pressure of the steam as it enters the steam chest of the second stage.

5 In the actual steam turbine, we find that the quantity of heat transformed into work is only 40 per cent to 70 per cent of the heat theoretically available for transformation by isentropic expansion. A small portion of this is lost by gland leakage, radiation and bearing friction. The most of the missing energy, however, has been retransformed into heat by eddying, fluid friction, blade leakage, etc., and appears in the steam, increasing its entropy. We may assume that in actual practice 60 per cent of the energy theoretically developed in the first stage of this turbine, or 96.0 B.t.u., would be transferred to to the rotating member, and about 40 per cent, or 64.5 B.t.u., would be retransformed into heat, making the heat content of the steam entering the stage, $1193.3 - 96.6 = 1096.7$ B.t.u. This would give for

the entropy of the steam at the pressure of 18.4 lb., the value 1.655. The heat content of steam of 1.655 entropy and 1.005 lb. pressure is 925.0 B.t.u., which gives for the heatdrop in the second stage 1096.7 − 925.0 = 171.1 B.t.u. This is more than 6 per cent greater than the heat drop assumed for the first stage. It is plain that in order to equalize the heat drop in the two stages, the pressure range in the first stage must be increased at the expense of that in the second stage. It is also evident, as Professor Peabody has pointed out, that the efficiency of each stage is less than the efficiency of the turbine as a whole, the larger efficiency of the turbine being accounted for by the fact that the steam entering the second and each subsequent stage contains an extra quantity of heat as a result of the inefficiency of the preceding stages, which is available for transformation into work of the succeeding stages.

6 It will be found by trial and adjustment that if the theoretical heat drop per stage, which we may designate by the symbol $\frac{\Delta H}{n}$, be multiplied by the empirical factor $1 + K$, we will have the heat drop per stage which will give an actual equality in the quantity of energy developed in each stage. In the above empirical factor, the value of K is found by the equation

$$K = 0.00056 \left(\frac{n-1}{n}\right) \Delta H \, (1-E)$$

In this equation, n is the number of stages, ΔH is the total heat drop theoretically available by adiabatic expansion between the initial and terminal pressures, and E is the probable thermal efficiency of the turbine. The value of E may be obtained from the equation

$$E = \frac{2545}{S \times \Delta H}$$

In this equation, S is the probable steam consumption per horsepower per hour of the turbine.

7 In the turbine which we are designing, we have assumed the value of this efficiency to be 0.60, the heat drop to be 322.2 B.t.u. and the number of stages to be two.

8 Substituting these values we find

$$K = 0.00056 \left(\frac{2-1}{2}\right) 322.2 \, (1 - 0.60) = 0.036$$

The probable heat drop per stage will therefore be

$$\frac{322.2}{2}(1 + 0.036) = 167.0 \text{ B.t.u.}$$

Allowing this drop in the first stage, we will have for the heat content after the first isentropic expansion $1193.3 - 167.0 = 1026.3$ B.t.u. From the entropy table, the pressure of the steam entering the second stage will be 16.86 lb. since this is the pressure corresponding to the entropy 1.56 and the heat-content 1026.3. Since the efficiency of the turbine is 60 per cent, the heat transformed into work is 60 per cent of the theoretical heat drop and the heat transformed into work per stage is

$$\frac{\Delta H}{n} \times E = \frac{322.2}{2} \times 0.60 = 96.7 \text{ B.t.u.}$$

Subtracting this quantity from the initial heat content, we have for the heat content of the steam entering the second stage of the turbine $1193.3 - 96.7 = 1096.6$ B.t.u. We therefore have for the entropy of the steam entering the second stage the value 1.663. Assuming the same heat drop in the second stage to be the same as that in the first stage, we will have for the heat content of the steam leaving the second set of nozzles, $1096.6 - 167.0 = 929.6$ B.t.u. The pressure of steam having 929.6 B.t.u. heat content at the entropy 1.663 is found to be 1.005 lb. which gives a complete check on our work and shows the calculations to be correct.

9 If it is desired to find only the pressure of the steam as it enters each stage of the turbine, it will be found that we may proceed in the following manner: From the initial heat content of the steam, which we will designate by the symbol H_1, we will subtract the quantity

$$\frac{\Delta H}{n}\left[1 + 0.00056\left(\frac{n-1}{n}\right)\Delta H\,(1 - E)\right] = h_1 \ldots\ldots [1]$$

and write

$$H_1 - h_1 = H_2 \ldots\ldots\ldots\ldots\ldots\ldots [2]$$

From the temperature entropy table determine the pressure of steam of the initial entropy, having for its heat content H_2. This will be the pressure of the steam entering the second stage. Let us now subtract from H_2 the quantity

$$\frac{\Delta H}{n}\left[1 + 0.00056\left(\frac{n-3}{n}\right)\Delta H\,(1 + E)\right] = h_2 \ldots\ldots [3]$$

and obtain

$$H_2 - h_2 = H_3 \ldots\ldots\ldots\ldots\ldots\ldots [4]$$

The heat content, H_3, together with the initial entropy of the steam. will determine the pressure of the steam entering the third stage. The pressure of the steam entering the fourth, fifth, etc., stages is obtained in a similar manner except that we must substitute the quantities $\frac{n-5}{n}$, $\frac{n-7}{n}$, etc., for the quantity $\frac{n-1}{n}$ in [1] to obtain the quantities h_3, h_4, etc. When performing this operation in the case of any particular turbine, it will be found that the value

TABLE 1 METHOD OF DETERMINING PRESSURES

$\Delta H = 322.2$ $\frac{\Delta H}{n} = 53.5$ $0.00056\ \Delta H\ (1-E) = 0.072$

$\frac{n-k}{n}$	$0.072\ \frac{n-k}{n}$	h	H	Pressure
5/6	0.060	56.7	1193.3	164.8
3/6	0.036	55.4	1136.6	81.1
1/6	0.012	54.5	1081.2	37.9
−1/6	−0.012	52.8	1026.7	16.9
−3/6	−0.036	51.6	973.9	7.03
−5/6	−0.060	50.3	922.3	2.81
			872.0	1.00

of h is greater than $\frac{\Delta H}{n}$ for the $\frac{n}{2}$ high-pressure stages, and less than $\frac{\Delta H}{n}$ for the $\frac{n}{2}$ low-pressure stages. So far as the writer is aware, there is no particular reason why this method should give correct results, but experience shows that it does do so.

10 In order to illustrate the method of determinating pressures, we will determine the pressure in each of the stages of a six-stage turbine working between the same limits of pressure as the turbine whose design we have already considered. As before, the initial heat content is 1193.3 and the entropy 1.56. In order to make the application of the method more clear we will arrange the results in tabular form. We will assume that the efficiency, as before, is 0.60. The adiabatic drop will, of course, be 322.2 B.t.u. The work of computation is shown in Table 1.

USE OF MOLLIER'S DIAGRAM

11 The same method may be applied in graphical form to the solution of this class of problems when Mollier's total heat-entropy diagram is used. The writer believes that designers will find the following the best method to use for the graphical solution of this

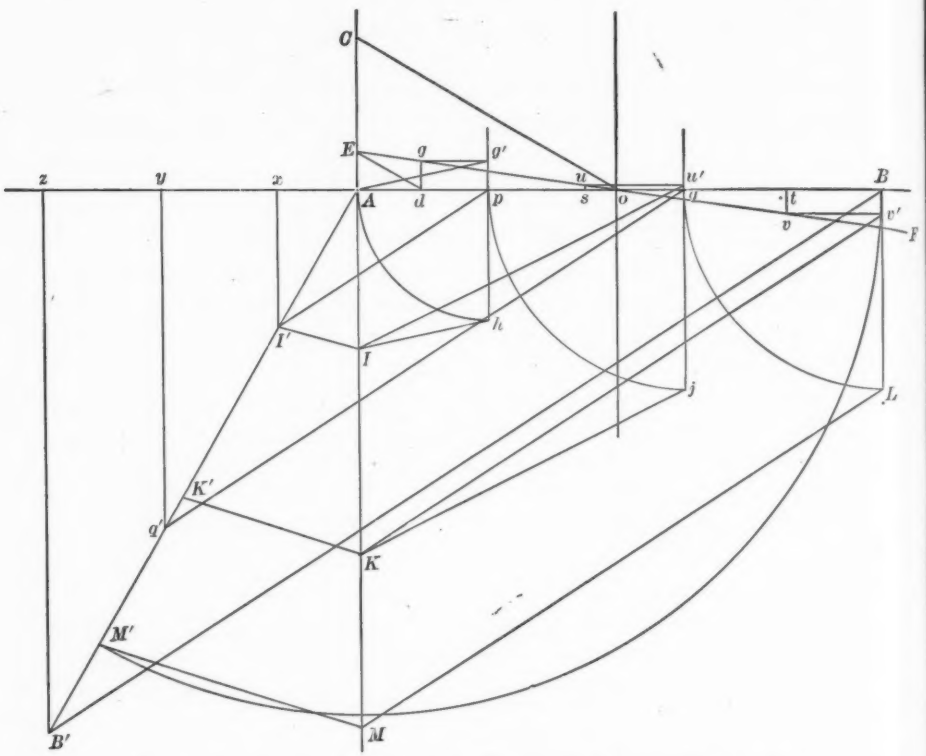

FIG. 1 GRAPHICAL CONSTRUCTION BASED ON MOLLIER'S DIAGRAM
ANGLE COA IS MUCH LARGER THAN IT SHOULD BE IN ORDER TO MAKE THE CONSTRUCTION CLEAR

problem, when the amounts of power developed by the different stages are unequal, as is sometimes the case. It is assumed that the diagram used is that accompanying Marks' and Davis' steam tables. The diagram, to have real value in the designing office, should be pasted on a well seasoned drawing board and covered with a sheet of very thin celluloid. Knowing the initial pressure and quality, or superheat, of the steam, we find on the diagram the point (*A* in Fig. 2)

representing this state, and through this point on the celluloid covering, draw a constant-heat (horizontal) and a constant-entropy (vertical) line. We will hereafter designate these two lines by the symbols H_1 and N_1 respectively. Find the state point of steam after adiabatic expansion to the exhaust pressure (H_4 in Fig. 2) by finding the intersection of N_1 with the exhaust-pressure line. The distance between the initial and final state points, of course, represents the quantity ΔH on the scale of the heat diagram. On a sheet of good detail paper draw the horizontal line AB as shown in Fig. 1, having a length equal

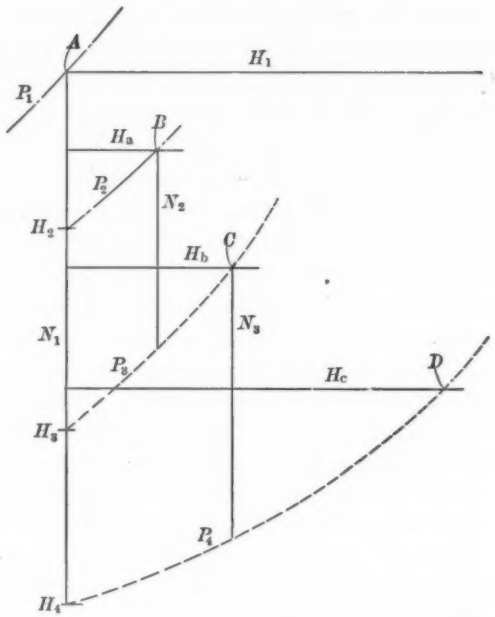

FIG. 2 SHOWING USE OF MOLLIER'S DIAGRAM

to this distance, and bisect it at O. At A, erect a perpendicular, making the length Ac equal to $0.00056\ (\Delta H^2)\ (1-E)$. This may be easily done by setting a protractor at an angle whose tangent is $0.00112\ \Delta H\ (1-E)$ and drawing line Oc through O to intersect Ac at c. Divide AB into the same number of segments as the turbine is to have stages, making the length of each segment proportional to the amount of power which is to be developed in the corresponding stage.

12 Points p and q in Fig. 1 represent the division points between the segments. Bisect each segment to locate the mid-points d, s and

t. Draw de parallel to Oc. Draw ef through O. Erect short perpendiculars at d, s and t, to intersect ef, at g, u and v. Erect perpendiculars through A, p, q and B. Draw horizontals through g, u and v to intersect the perpendiculars through p, q and B, at g', u' and v'. With p as a center, strike arc Ah. In like manner, with q and B as centers, strike arcs pj and ql. Draw Ag', and then hi parallel to it, intersecting the perpendicular through A at i.

13 In the same manner, draw jk and lm parallel respectively to $u'i$ and $v'k$. If the segments into which AB have been divided are all equal, we are now prepared to determine from Mollier's heat diagram the pressures in the steam chests of the several stages in the following manner: Through lines N_1 on the celluloid covering of the heat diagram, draw short lines, H_2, H_3, and H_4 as shown in Fig. 2, making the distances of these several lines from line H_1 equal to Ai, Ak, and Am respectively. The intersections of these lines with line N_1 will determine on the heat diagram, the pressure of the steam in the steam chests of the several stages, or in the exhaust. If the diagram is correctly drawn, Am will be equal in length to AB, and the exhaust pressure found will be that originally fixed upon.

14 If however, the segments are of unequal length for any reason, as would be in the case if the diameters of the several rotating members are unequal, we would find that Am would not be equal to AB, and the exhaust pressure would be incorrect. In order to determine the pressure of the steam entering each stage under these conditions, we must alter our diagram in the following manner: about A as a center, strike an arc in the manner indicated, having the length $A'm'$ equal to AB. Through point A, with a 60-deg. triangle, draw $A'm'$ intersecting the arc at m'. Draw mm', and then draw kk' and li' parallel to it. By following the same procedure as was outlined in the preceding paragraph, but using distances Al', Ak' and Am' to locate H_2, H_3 and H_4, we may readily determine the correct value for the pressure of the steam entering any stage of the turbine.

15 If it is desired to determine from the diagram all of the properties of the steam as it enters each stage of the turbine, and to check the work, we may proceed as follows: Note that Ai' is the actual heat-drop in the first stage, and that the actual heat-drop in each succeeding stage bears the same proportion to its segment as Ai' does to the segment Ap. We may accordingly determine the actual heat drop in each stage by drawing pi', and then drawing qq' and BB' parallel to it, intersecting Am' at q' and B'. We will now have Ai' equal to the actual heat-drop in the first stage, $i'q'$ equal to the actual heat drop

in the second stage and $q'm'$ equal to the actual heat-drop in the third stage. We may complete the design in the following manner: Lay off to the left a distance AZ equal to $E \times AB$ where E is the efficiency of the turbine expressed as a fraction. Draw $B'Z$, and parallel to it $q'Y$ and $i'X$. On the celluloid covering of the diagram draw line H_a parallel to H_1 and at the distance AX below it. Through the point B, determined by the intersection of H_a and the pressure line P_2 determined by H_2, draw line N_2 parallel to N_1. The point B is the state point of the steam entering the second stage. From this point measure downward the distance $i'q'$ on the line N_2. The point so found should fall or the pressure line P_3, determined by H_3. Draw H_b parallel to H_1 and distant Ay from it, and find its intersection at C with the pressure line P_3, determined by H_3. This will be the state point of the steam entering the third stage. Through it draw N_3 parallel to N_1, and from it measure downward on N_3 the distance $q'B'$. The point so obtained should fall on the exhaust-pressure line. Draw H_c distant Ax from H_1 and find its intersection at D with the exhaust-pressure line. This intersection is the state point of the exhaust steam.

16 It is believed that after the designer has once familiarized himself with the method of constructing this diagram, the time required to perform carefully and accurately the directions given and to make all the determinations necessary, will be comparatively short, certainly not more than an hour in the case of a four-stage turbine, and that the method will eliminate much of the tedious labor which is necessary when the method of successive approximation is used in performing this work.

THE MECHANICAL ENGINEER AND PREVENTION OF ACCIDENTS

By John Calder

ABSTRACT OF PAPER

The paper discusses the nature and incidence of industrial injury, its prevalence and high rate, in the United States in particular, and the present general desire for better conditions of safety. It analyzes the chief causes of injury as revealed from a study by the author of a large number of verified casualties and recommends practicable measures calculated to reduce the present numerous fatalities and injuries. It discusses in particular the important services which the mechanical engineer, both as an executive and constructor, can render in exercising his ingenuity to avoid industrial accident.

The paper contains a number of practical safeguarding illustrations from the field of machine building, equipment installation, transmission plant and especially dangerous machines and processes, and concludes with suggestions for administrative and remedial precautions.

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THE MECHANICAL ENGINEER AND PREVENTION OF ACCIDENTS

By JOHN CALDER, ILION, N.Y.

Member of the Society

The conservation of our natural resources has rightly received attention from the Society, but with one exception, the elements hitherto considered have been of a purely material order. The exception is the valuable and timely monograph on The Safeguarding of Life in Theatres which formed the Presidential Address of John R. Freeman at the Annual Meeting of 1905.

2 Yet the preservation, as a national asset, of the lives and limbs of our citizens and industrial workers is more urgent and vital than any steps taken to insure adequate means of subsistence and industry for future generations and an attempt has been made in this paper in a necessarily imperfect way, to treat of the larger field of industrial safeguarding.

3 Accident clauses, wise and less wise, have been included in the labor laws of the various States for some years, but the provision for administering these laws effectively has always been inadequate. Indeed it would seem as if the earlier legislation of this nature, modeled on the latest practice of the older civilizations, was at the time of its enactment considerably in advance of public sentiment. At least, until quite recently, the subject of prevention of accident has signally failed to obtain really serious consideration from employers and employees in general and most safeguarding progress has been due to official compulsion.

4 Legal obligation to safeguard thoroughly has not succeeded in preventing avoidable accidents to any great extent except in the relatively few cases where persuasion and enlightenment have accompanied it. On the other hand, civil liability for the consequences of industrial injuries has been steadily increasing and to the necessarily

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, 29 West 39th Street, New York. All papers are subject to revision.

limited efforts of a few State officials, there was added the pressure of insurance underwriters upon employers when accident risks became too onerous. Employers liability is receiving at the present time the careful attention of some of our best legal and business minds, but in this paper it is prevention, not cure or compensation, which is emphasized.

5 The subject of accident prevention, which has by no means been neglected by many careful plant executives, is now coming to the front on that wave of humanitarian consideration which is noticeable everywhere. It is the hope of the writer that mechanical engineers as a professional body will cordially identify themselves with a cause in which they, more than any others, can achieve much good.

6 On its educational and sentimental aspects the public and press of the East have had their interest awakened to some extent by the efforts of the American Museum of Safety Devices, the National Association of Manufacturers, the National Civic Federation and others. On the strictly practical side the broad-based safeguarding work initiated in all its plants at a large outlay by the United States Steel Corporation has received deserved publicity.

7 At the same time the successful operation of thorough preventive measures has been going on unnoticed for years at some relatively few individual works, but these have formed quite a minority among the many plants incurring accident risks which were imperfectly safeguarded. It is the object of the present paper to initiate a discussion of accident prevention by stating in some detail the principles of industrial safeguarding as they have presented themselves to the author and illustrating the art freely by examples drawn chiefly from his experience in plant management.

8 In study and in legislation on this matter we have lagged considerably behind Great Britain, Germany and France, which countries more than thirty years ago began to enforce with strictness and excellent technical judgement, the existing laws for safeguarding industrial workers. In recent visits to mechanical plants in various parts of Europe the author noticed considerable advance over the high standard obtaining there twelve years ago, in protecting the worker from the incidental risks of his employment and from his own ignorance and carelessness.

9 Industrial accident reporting is still very incomplete in the United States and the Federal Government's accident statistics are necessarily below mark; yet Bulletin No. 78 of the Bureau of Labor, September 1908, states that, among adult wage earners alone,

the yearly mortality from accidents is between 30,000 and 35,000. The non-fatal injuries inflicted can not be much less than 2,000,000 additional.

10 These staggering but undoubtedly conservative figures of a single year of peaceful industry far exceed the killed and wounded of several great military campaigns, and when compared with the more thorough foreign accident returns, give us just cause to inquire why we should be so far behind in conserving the lives and health of the industrial worker. The figures take no account of the many casualties affecting women and young people and they are rarely looked into as a whole; but when the truth about them can be recorded it will stir up the most indifferent.

The Mechanical Engineer and Accidents

11 From a comparative study for some years of the conditions of safety under which European and American industries are carried on, the author has come to the conclusion that the progress in this direction so desirable in the interests of the race cannot be attained entirely by acts of legislatures, pressure from State officials, warnings and recommendations from casualty insurance corporations and admonitions from sociologists, valuable though these are.

12 The principles of safeguarding and safeworking in industry should be as much a part of the economic education of the young engineer as those of efficiency and conservation in other directions. The author believes that many engineers enter on responsible control of operations and industries with little or no realization of the employment risks involved. Such a consciousness comes in time, but it is often through the painful and harrowing experience of avoidable accidents and fatalities which were not prevented.

13 The scientific study as a matter of course and the solution by the mechanical engineer of individual problems of safeguarding, supervision and instruction of employees as they arise in their daily routine will do more than all other existing agencies to bring about satisfactory results. The progress of the art of preventing industrial accident, wherever that is practicable, depends very largely upon the amount of intelligent interest manifested in the subject by members of the profession whether engaged in plant maintenance, the manufacture of tools and other apparatus, invention of safeguards or in works administration. In such matters as this the attitude and action of the executive is all-important and gives the keynote to the whole plant.

14 The author wishes to make it clear, however, that all industrial accidents are not considered preventable, either by employer or employee, and that, of those that may be avoided, some do not fall strictly within the engineer's province and a large portion is directly within the control of the injured themselves. Nevertheless, a considerable number of casualties remain which are the most serious in their consequences to operatives and employers alike and which can and ought to be prevented by mechanical and executive precautions and the exercise of the same faculties which the engineer efficientlv applies to his other problems.

15 It is believed that, by proper supervision and precautions in all plants and industrial processes and the cultivation of greater care by operatives, at least one-third of the present annual sacrifice of life and limb can be prevented, thus increasing our national assets, and a large amount of human suffering and sorrow obviated. For this belief there are good practical grounds of which one typical instance may be cited.

16 In one plant which had a yearly average of 200 accidents a good deal of consideration was given to preventive measures, both mechanical and administrative. As a result of such steps, which reduced the earning opportunities of no employee, the number of accidents for the last annual period was only 64, with the following analysis after close inquiry into each case:

17 In no instance had any accident occurred in a year's time from negligence of the employer and in only one case was the inquiry contributed to by the negligence of a foreman or responsible overseer. In 25 of the cases the accident was caused solely by the negligence of the person injured and in the remaining 38 cases the occurrence was purely fortuitous, accidental and non-preventable in the most literal sense, no blame being attachable to anyone. The latter evidently represents the unavoidable trade risk of this particular plant. Yet the actual risk, before safeguarding and instruction of employees was seriously undertaken was nearly six times as great and the resultant risk including all cases of carelessness on the part of operatives was less than one-third the original rate. This experience has been repeated in many cases.

The Causes of Accidents

18 In illustrating in the present paper what the mechanical engineer may achieve in this department of the conservation movement

a definition of "accident" and a review of the chief causes of industrial injuries are in order. The word accident in relation to industry is not specifically defined by any statute, but in the legislation of both the old and the new world it has the popular significance of any unforeseen and usually sudden occurrence which results in bodily injury to any person while present at the work-place or even within the boundaries of the employer's premises.

19 The injury, to be reportable as an accident, need not arise out of or in connection with the employee's assigned duties. It is the fact of injury, not the cause, which generally makes an accident reportable under the labor laws to the civil authorities. In some cases a time-limit of absence from work due to accident has been used by statute to eliminate trivial injuries from reports. It is clear, however, that an employee may be lucky enough to escape with very slight bodily injury from a machine or process properly classed as dangerous and that consideration of the safeguarding of the same should not be overlooked because of that fortunate circumstance.

20 For this reason the legislative tendency in all countries now is to call for the reporting of every injury without regard to its extent or the incapacity for work entailed. In this way the official investigator and the work's mechanical engineer are both provided immediately with the necessary data regarding the accident, irrespective of its varying consequences.

21 In analyzing many thousands of industrial accidents, with a view to devising remedies, the author has found the following to be the chief causes: ignorance, carelessness, unsuitable clothing, insufficient lighting, dirty and obstructed workplaces, defects of machinery and structures, and absence of safeguards. In current popular comment on the wastefulness of life and limb in our industrial régime little regard is paid to the facts underlying accident, but well considered action must be based solely on these of which some account follows.

22 Fire, steam generators and other vessels under pressure, electricity, railroads and elevators as contributing factors to accident are omitted from present consideration because they are, of all industrial dangers, those upon which mechanical and other engineers have already lavished attention. It is significant that it is chiefly in cases where property, as well as persons, is liable to injury that preventive measures against accident have as yet been generally and efficiently elaborated.

IGNORANCE

23 In spite of ample facilities now afforded to all for the acquisition of some knowledge of mechanical principles, the author has found some superintendents, a number of foremen, many operatives and not a few managing owners of smaller plants grossly ignorant of the nature of the forces and mechanical arrangement which it is in their power either to control, or to set free with resulting danger to themselves and others.

24 Illustrations of this will occur at once to all works' excutives and it has been to the author a constant matter for regret that organized labor with its unique opportunities has done so little to supplement or complete the mechanical education of its members. Accidents due to the culpable as well as excusable ignorance of supervisors, engineers, millwrights, elevatormen, firemen and guardians of general facilities are frequently very serious and nothing but administrative vigilance in selecting and instructing these employees for their own special risks will suffice to prevent such occurrences.

CARELESSNESS

25 Sometimes combined with ignorance, sometimes sheer thoughtlessness, folly or horseplay, carelessness by operatives stands highest as a cause of industrial accident from the results of which nothing external can do much to shield the worker and those whom he sometimes involves. All plant executives know that many things workmen do and suffer under this head would hardly be credited by the sympathetic outsider with no knowledge of the facts.

26 It is the experience of the author that the bright and nervy American workman, so admirable in many respects, is easily first in taking foolish and wholly unnecessary chances with his life and limbs; chances which in no way add to his efficiency or his earnings. The exaggerated ego manifests itself frequently in ostentatious independence full of danger to himself and to others. The maintenance of strict discipline in the shops, the adoption of salutary punitive measures and the firm elimination of the dangerous employee is all that can be done, in addition to a campaign of education throughout the plant.

UNSUITABLE CLOTHING

27 Accident is caused at many machine parts which are necessarily exposed near the operator and with which he would never come into dangerous contact but for unsuitable or neglected clothing. The ragged sleeve ends, loose ties and open jackets of untidy machinists have again and again been wound upon seemingly trivial parts in motion and through the powerful effect of coil friction have inflicted frightful and often fatal injuries.

28 Not a few survivors have to thank the inferior strength of the usual overall or dust jacket for escape. The large extent to which females are finding agreeable and profitable employment at light repetition machine work calls for special and obvious precautions regarding dress and general tidiness which need not be detailed here.

INSUFFICIENT LIGHTING

29 Insufficient lighting is a cause of numerous accidents, particularly serious and fatal falls. The author has observed that a maximum of accidents occurs towards the close and beginning of each year, that is during November, December and January, the months of minimum daylight. Fig. 1 shows the seasonal distribution for three successive years of about 700 deaths annually from industrial accidents which were reported with other injuries from an area embracing 80,000 plants of varying extents.

30 The influence of the duration and intensity of natural light in working hours on fatal and serious accidents is particularly noticeable in such founding, bridgebuilding, shipbuilding, engineering, and steel and iron works and other operations as have to be carried on within large spaces, often entirely in the open air and not easily illuminated artificially to the exclusion of deep shadows.

31 Within plant buildings the intensity of artificial lighting at the cutting point of tools, for instance, and on very limited machine-tool or bench areas is frequently far above actual requirements and a source of much physical discomfort, while all around the operative a semi-darkness prevails which has a blinding effect in the sudden transitions of the vision required by his employment.

32 It has been found by exact photometric observations of shop-lighting conditions both during the day and at night, that the concentrated illumination by means of shades of ordinary 16-c.p. incandescent units on cutting tools in machines and the area near them

is often several times the intensity of ordinary daylight on the same parts. It is very difficult to convince the operative that he is suffering from too much light at any place and the call is constantly for more light.

33 What is wanted from the safety point of view and also, the author believes, from considerations of power economy, is the elimination by good illuminating engineering of this excessive hard light on

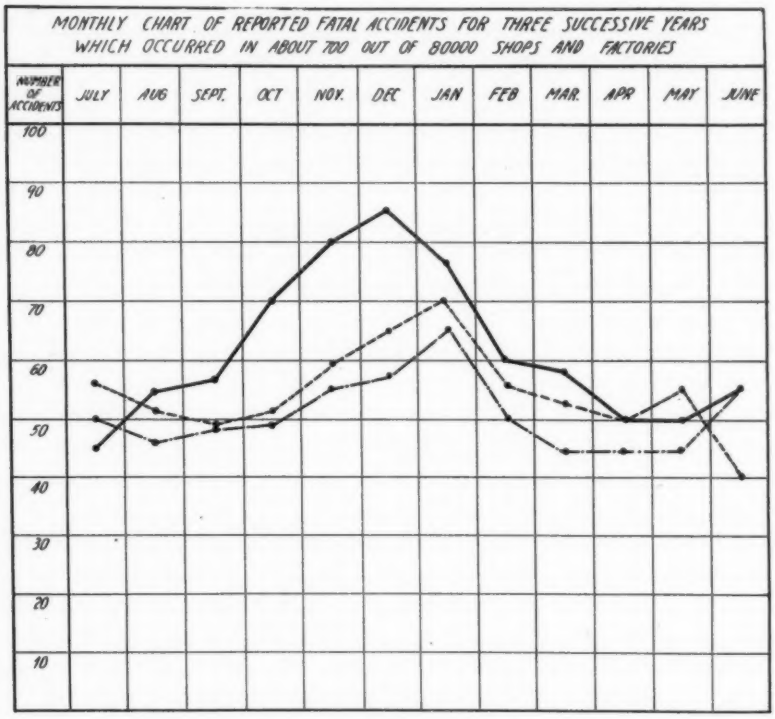


FIG. 1 INFLUENCE OF DAYLIGHT ON ACCIDENT

spots only, which causes eye-strain and poor vision of surrounding areas with resulting accident. A more generally diffused light of less unit intensity is now easily obtained by the use of fewer but larger screened units experimentally located to suit varying shop requirements and reflecting from whitened wall and ceiling surfaces. The mechanical engineer administering industries or designing plants can do much to reduce the accident risk from this cause.

DIRTY AND OBSTRUCTED WORKPLACES

34 Dirty and obstructed work places are closely allied to defective illumination as a source of accident. The literal "shedding of light" on waste and rubbish is often the sure forerunner of their removal and avoidance of accidents, due to them. Workplaces often retain unnecessarily dirty and obstructed environments causing stumbling and falls and similar accidents, and every management should see to it that the cleaning of floors and passages and the removal of wastes is systematically provided for.

35 Sometimes this condition is due to the habits of the employee himself and he has to be educated to better ways. At other times floor space is economized and machines and workers are crowded together without due regard to safety in moving about in the confined area. Almost all our mechanical operations can be conducted under pleasanter and safer conditions than at present, so far at least as light and cleanliness are concerned. The tidy shop is less costly in the long run than the dirty one and has a noticeable effect on the morale of the whole establishment.

DEFECTS OF MACHINERY AND STRUCTURES

36 A good deal of eloquence has been expended from time to time on the assumed inherent and deadly defects in machinery and structures used in the arts. These indeed contribute to some serious and a number of minor casualties but to nothing like the extent commonly alleged. Altogether apart from the question of specific safeguarding provisions, it has been infrequent in the author's experience to find machines or processes in operation which are essentially dangerous because of defective design or arrangement, or from lack of repairs or renewals, and thereby liable to break down and cause injury.

37 It certainly does not pay any employer to keep a defective tool in operation; nor is it in the interest of the employee, particularly if he is paid by the task, to use imperfect apparatus which reduces his possible earnings. On the other hand, it is by no means infrequent to find workmen, who have their choice of the best materials and apparatus and who possess the intelligence to apply these correctly, showing a striking disregard for their own safety and that of others, especially in framing structures and arrangements of a temporary nature.

38 This is particularly the case in outside work and especially in the building trades, but standardized methods are gradually taking away the workman's initiative in this matter. Workmen persisting in practices of this nature should be eliminated as unfit and dangerous employees and the ability of any untried operative to construct safe facilities to be used by himself and others should never be taken on trust.

39 Overloaded machines and structures, decayed gangways, worn out floors and stair treads, unannealed chains and hooks, frayed and stranded ropes and tackle and a host of minor industrial equipment are items which should pass under systematic and intelligent review from time to time as possible sources of accident.

40 These it may be said are commonplaces, but they are also common neglects both on the part of executives and of workmen themselves. Such attention to safety need be no burden. In the daily routine of plants, whether large or small, if machinery and other equipment is properly selected and installed, and hurry calls for repairs promptly responded to by competent people, and the employees made to feel that suggestions as to real or even imagined defects in the apparatus they must use are welcomed, the team work of good organization will help greatly to eliminate avoidable accidents from these causes, which are usually a reflection upon the executives.

The Possibilities of Safeguarding

ABSENCE OF SAFEGUARDS

41 The absence of safeguards, though not the most prolific cause of accident in plants, closely concerns the mechanical engineer who holds the possibilities largely in his own hands. In the eyes of the public and non-technical investigators it is of first importance. Though our industrial life is characterized by a steady extension of the factory system of production and an increased division of labor using mechanical aids, the accident list need not increase pro rata.

42 In many cases of injuries to operatives caused by the absence of a possible safeguard it will be found that it has been removed, or rendered ineffective by the employee for lack of supervision in such matters or that protection has never been provided. Safeguarding absent at one machine is sometimes actually afforded elsewhere under the same roof and the accident is due to the operation of the principle, that what is permitted to be everybody's or anybody's business is in

daily life nobody's business. The safety engineering of no plant should be left to the haphazard initiative of a number of individuals.

43 Consideration of what the mechanical engineer can contribute to this end naturally falls into two divisions:

a The efficient safeguarding which he may design as an integral part of the machine tools and other apparatus supplied by him for use in the arts.

b The safeguarding which he may later devise and supply as the mechanical engineer or executive of plants using power apparatus and other equipment capable of inflicting injury as installed and which cannot be intelligently protected until all related apparatus is in position and the operating conditions for employees fully apparent.

44 Some degree of finality is necessarily attainable in the simpler forms of safeguards about powerhouses, transmission machinery and dangerous details common to all machines, and most failures to prevent accidents from these are due to lack of consistency and thoroughness in applying the recognized remedies. The safeguarding of some especially dangerous machines and processes is to some extent evolutionary and where it is legally obligatory it must be of the safest type known. So far as statutory compulsion in any one State is concerned the requirement to safeguard the more powerful machine parts is usually absolute. In the much larger field of machine operations in detail, it is conditioned by proof of danger and necessarily by practicability.

The Machine Builder and Safeguards

45 The machine toolbuilders, many of them members of this Society, have already accomplished a great deal of most useful safeguarding, particularly in protecting the workman from the dangers of toothed gears in metal working and other tools. Now and again, however, a so-called guard is encountered which is simply no guard at all but rather a snare, and which shows conclusively that its designer had appearance rather than utility in mind.

46 Fig. 2 illustrates this, the pinions *PP* being securely covered on the top which is the outrunning and safe side by semi-circular flanged hoods, whereas the intaking and dangerous parts of the gears *WW* are unprotected and have gripped the clothes and limbs of unsuspecting operatives. The covering of the outrunning sides of gears

is often desirable to prevent the lodging of chips and waste in them, but they are usually harmless when exposed. Fig. 3 shows the proper gear protection for the machine illustrated.

47 Numerous instances might be cited of the vague notion expressed in some current machine designs that anything which looks like a cover for a part of a machine necessarily constitutes in daily service an efficient safeguard; sometimes no regard is paid to the actual direc-

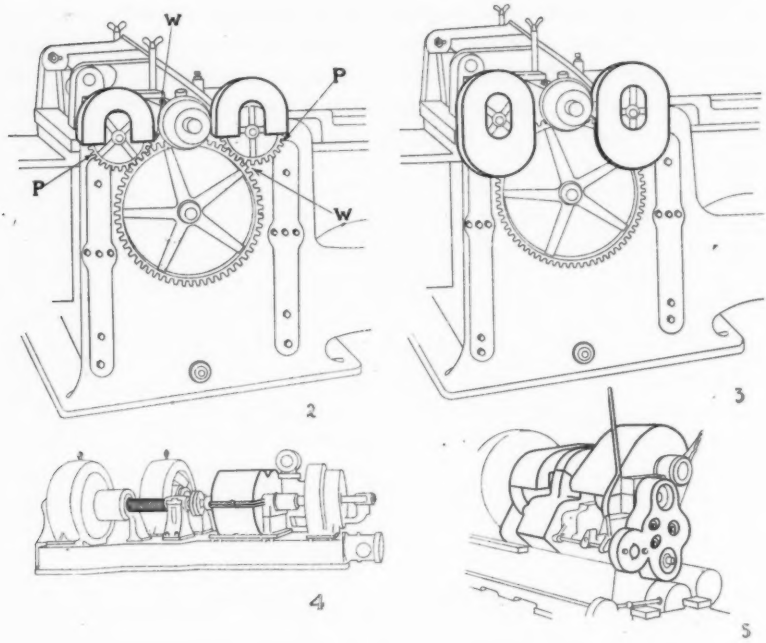


FIG. 2 DEFECTIVE GEAR GUARD
FIG. 3 SAFE GEAR GUARD
FIG. 4 GUARDED STEAM TURBINE
FIG. 5 LATHE BUILDER'S GUARD

tion of rotation or to reversal of motion or to the necessity in using the tool for frequently removing a clumsy cover which is as likely as not to be left off permanently. The real points of danger in daily operation need to be studied before a satisfactory protection can be provided.

48 A well designed and neatly applied guard on a machine is seldom a prominent feature and line sketches on which the safeguarding

is emphasized have been prepared by the author for this paper in order to secure the definition of the subject which is usually absent from half-tones made from photographs taken in the shops. Shafts and spindles, low pulleys, and belts, intaking sides of gears, narrow clearances between fixed and moving parts, couplings, projecting screws, nuts and pins and numerous similar risks on moving parts of machines as designed are best handled for protection by the machine builder. In any case the safeguarding of these when within the reach of the operator is usually obligatory upon the employer and always desirable. If absent from machines when delivered the provision of such safeguards naturally falls within the field of the mechanical engineer of the plant.

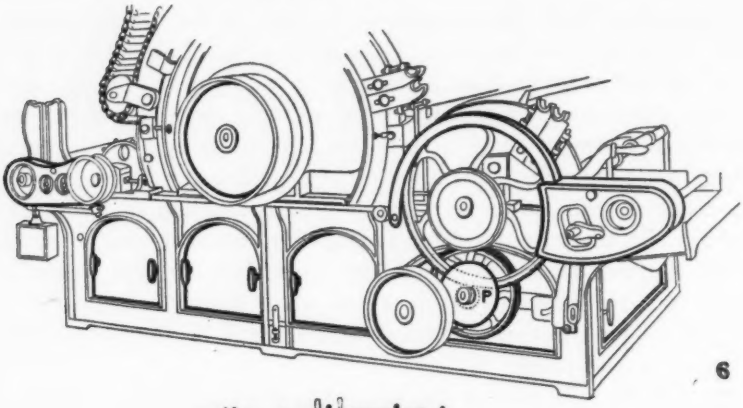
49 Within the scope of this paper the illustrations are necessarily limited to examples of safeguarding from only a few out of the many manufacturing industries concerned, but the principles outlined and the methods shown are applicable with occasional modifications wherever power-driven machinery is operated. Some examples are now given of the effective protection of the machine details just mentioned, a protection which can be and often is provided in greater or lesser degree by the makers of tools and of a large variety of apparatus used in the arts.

50 Fig. 5 is typical of what the tool builders are now doing in the way of neat and effective guards for the toothed gears of lathes and other apparatus, in which access for inspection is easy, and there is no temptation for the workman to throw the guard aside as cumbersome. An illustration of the safeguarding of complicated textile machinery by the makers is shown in Fig. 6.

51 In this machine panels and neat sectional guards of metal are used to minimize the risk of injury at all dangerous parts while in motion. At the same time access for cleaning and inspection at rest can be had in one movement at any protected part. To secure the results indicated careful planning and study of the working conditions are necessary, but where these are given by the mechanical engineer a solution meeting the conflicting conditions of use and safety is nearly always possible.

Guarding of Equipment Built into Position

52 Under the head of guarding of equipment built into position are embraced all power generators and a very large class of machines and industrial apparatus whose accident risks at dangerous parts de-



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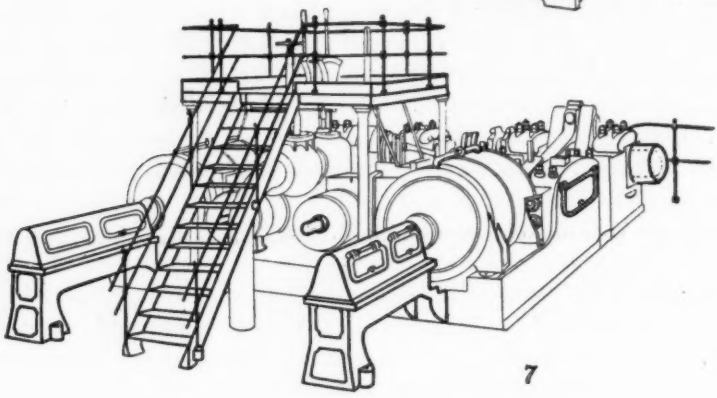

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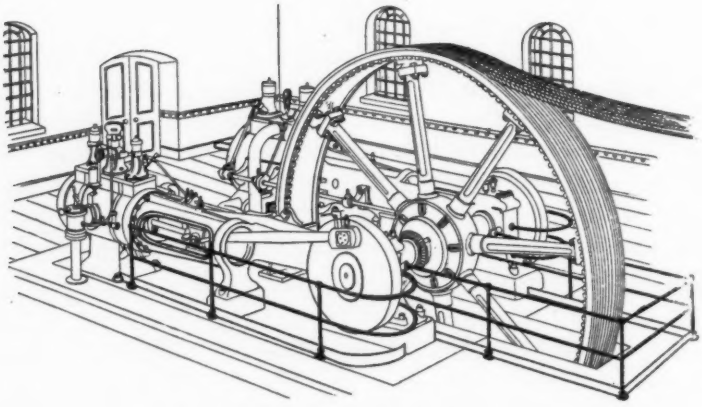

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FIG. 6 GUARDED COTTON CARDER
FIG. 7 GUARDED ROLLING MILL-ENGINE
FIG. 8 GUARDED TEXTILE ROPE-DRIVE ENGINE

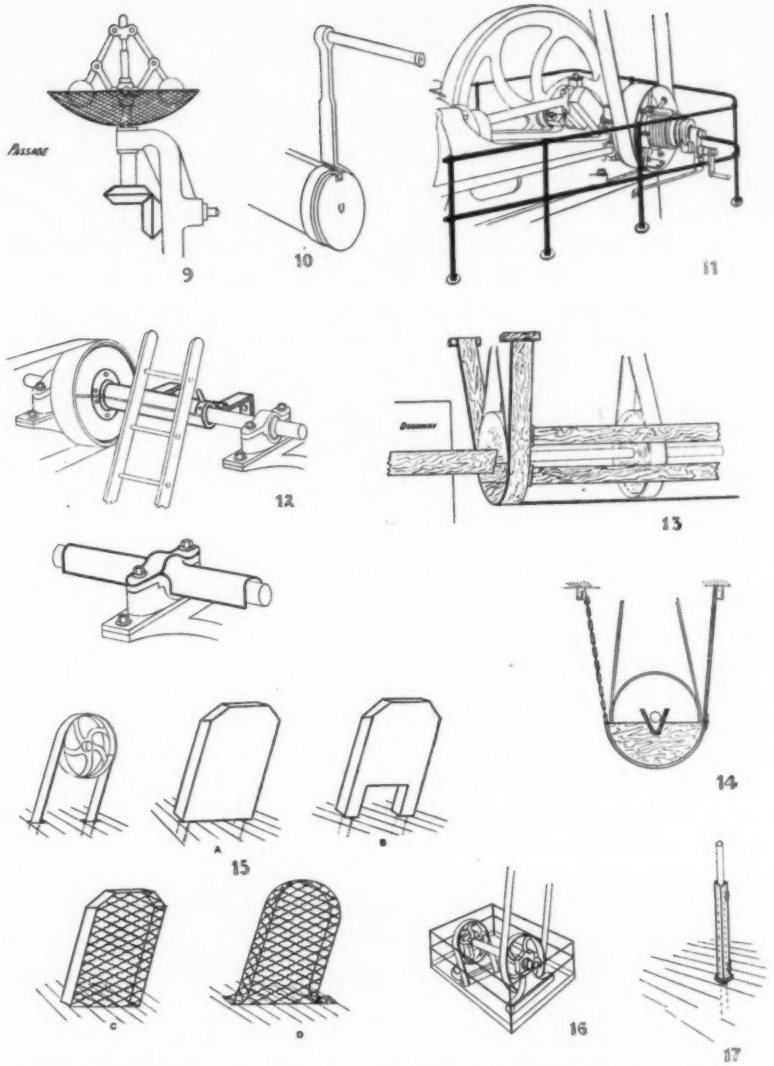


FIG. 9 GUARDED FLY-BALLS
FIG. 10 GAS ENGINE SAFETY STARTING CRANK
FIG. 11 GUARDED OIL ENGINE AND STARTING CRANK
FIG. 12 TRANSMISSION TUBE AND DISC GUARDS
FIG. 13 PERMANENT LOW OVERHEAD GUARDING
FIG. 14 DETACHABLE LOW OVERHEAD GUARDING
FIG. 15 SCREEN BELT GUARDS
FIG. 16 RAIL BELT GUARDS
FIG. 17 BOX SHAFT GUARD

pend upon the environment, the manner of installation and the precise nature of the workmen's duty around them. Enclosed prime movers such as the steam turbine, Fig. 4, and enclosed high-speed engines, and the extension of electric driving with purchased power, are reducing somewhat the number of small prime mover risks, but there are still in this country numerous reciprocating engines operated by steam, gas and oil and, of considerable age in some cases, which take annual toll of lives and limbs and are inadequately safeguarded.

53 Protection against accident at such apparatus is not secured as is sometimes supposed, by guarding merely the dangerous moving parts. All stationary portions of such prime mover structures as may cause injury to attendants and others should be equally included in the scheme of protection. In power houses the edges of all stairs, platforms, ladders and gratings should have low fenders of metal on both sides which will prevent nuts, bolts, tools and other small parts rolling off into the machinery or striking employees in their fall.

54 In addition a double metal railing not less than 3 ft. high and not nearer any moving part than 12 in. should be provided at all dangerous places such as crank and flywheel pits, etc., and at the inside and outside edges of all stairs and elevated platforms. The fulfilment of these requirements is shown in Fig. 7 on the starting platform, tail-rods and cross-heads of a rolling-mill engine; while the safeguarding of a textile rope-drive engine is shown in Fig. 8.

55 Engine attendants have necessarily to operate often where the footing is slippery and insecure and should be safeguarded when reaching out to bearings close to crank pits and other parts, or in passing around tail-rods and under low fly-balls and other similar parts which can and do cause many serious and not a few fatal injuries particularly on the older prime movers still in service. Figs. 9 shows a protection the author has used on governors and gas and oil engine safeguards are shown in Figs. 10 and 11.

56 The mechanical engineer administering a plant has rarely an opportunity to control and coördinate an equipment entirely modern in character and is often much exercised in safeguarding satisfactorily archaic forms of apparatus in which designers and makers are no longer interested. It is for this reason that some illustrations are shown of forms of protection which are not called for on later and safer designs and installation arrangements.

Guarding of Transmission Machinery

57 The safety of the connecting links between the power house or the shop motors and the individual machine tools and apparatus naturally calls for the mechanical engineer's attention. Transmission machinery, whatever its situation in relation to the floor level, has its accident risk conditioned by the necessity for any workman, having to touch or approach it in motion in the course of his duties.

58 The extensive use of multiplied motor drives, properly screened or at a safe elevation, has done away with many transmission belts, shafts, pulleys, collars and couplings in dangerous proximity to males and females at work in all of our more modern plants. The managers and mechanical engineers of many industries, however, have still to reckon daily with the accident risks of the older type of buildings and transmission arrangements and the latter when not safeguarded are sometimes the cause of horrible fatalities and ought to be closely scrutinized in every detail.

59 Metal tube and disc guards for shafting, bearings and pulleys requiring to be approached closely while in motion are shown in Fig. 12, while forms of protection for transmission in old plants with insufficient headroom are shown in Figs. 13 and 14. Seven feet clear of every moving part is considered the least height from the floor level without guarding and, even then, where a horizontal belt drives across a frequented passage at this minimum elevation it is well to have the lower side screened close to the belt to avoid injuries caused by "whipping" when the belt breaks.

60 Figs. 15, 16 and 17 show guards for belts and shafting driving through floors or at floor levels. Desirable and undesirable forms, respectively, of the shaft couplings, collars and set-screws of transmission apparatus are shown in Fig. 32, while in Fig. 18 are illustrated the safe and unsafe positions for idle belts which sometimes depend from shafts and cause numerous accidents. Fig. 18 also shows the manner in which an unshipped belt, allowed to travel on the shaft, seizes the shaft by its own friction, aided possibly at times by engendered electrification. The slack side *a* by contact with the tight side *b* is carried into the bight *c* and the shaft rolls up the two sides together usually breaking the belt, but in some cases of very light countershafting dislodging the latter and injuring the operatives beneath.

61 The use of the belt perch, Fig. 19, of which there are several forms, prevents the traveling of the belt when unshipped, and accident therefrom; obviates its unnecessary wear and its possible destruction when falling into the narrow gap between a pulley and a bearing. Fig. 21 shows one of several forms of belt replacement pole which does away with any close approach by the machine operator. Special care should be taken by the designers to see that all belt shifting and machine starting and stopping gears are positive in their action. Many accidents have occurred at machines through inefficient or defective fast and loose pulley and belt arrangements suddenly starting a tool which was under examination or adjustment.

Especially Dangerous Machines

62 The most difficult safeguarding problems for the engineer are those relating to numerous machines used in the arts, which, after the maker and installer have carefully protected all the details already described, are essentially dangerous at the operating point, if worked at all. The variety of uses to which such apparatus is put often precludes the application of a universal guard. Nevertheless protections claiming to be of all-round use are on the market for a number of especially dangerous machines.

63 No such machine, however, is effectively protected by any guard which hampers a workman, reduces his speed and earnings and has not been designed for the actual working conditions. Such inadequate apparatus is naturally removed by the workman or wholly or partially put out of action at the first opportunity and the particular safeguarding problem becomes the subject of a fruitless triangular controversy between the employer, the employee and the factory inspector.

64 To educate the employee to use caution and foresight about dangerous machines is difficult enough and it should not be rendered more so by calling upon him to work with an impracticable safeguard. What is needed in such a case is careful inquiry, by a competent engineer experienced in the study of safeguarding problems, into the conditions under which the employee has to operate and a solution, where such is possible, which will enable him to work with efficiency and safety or at least to reduce considerably the accident risk of his occupation.

65 For the purpose of illustrating the problem of the especially dangerous machine, the author has confined himself to examples of accident experiences with only four out of many classes of such ap-

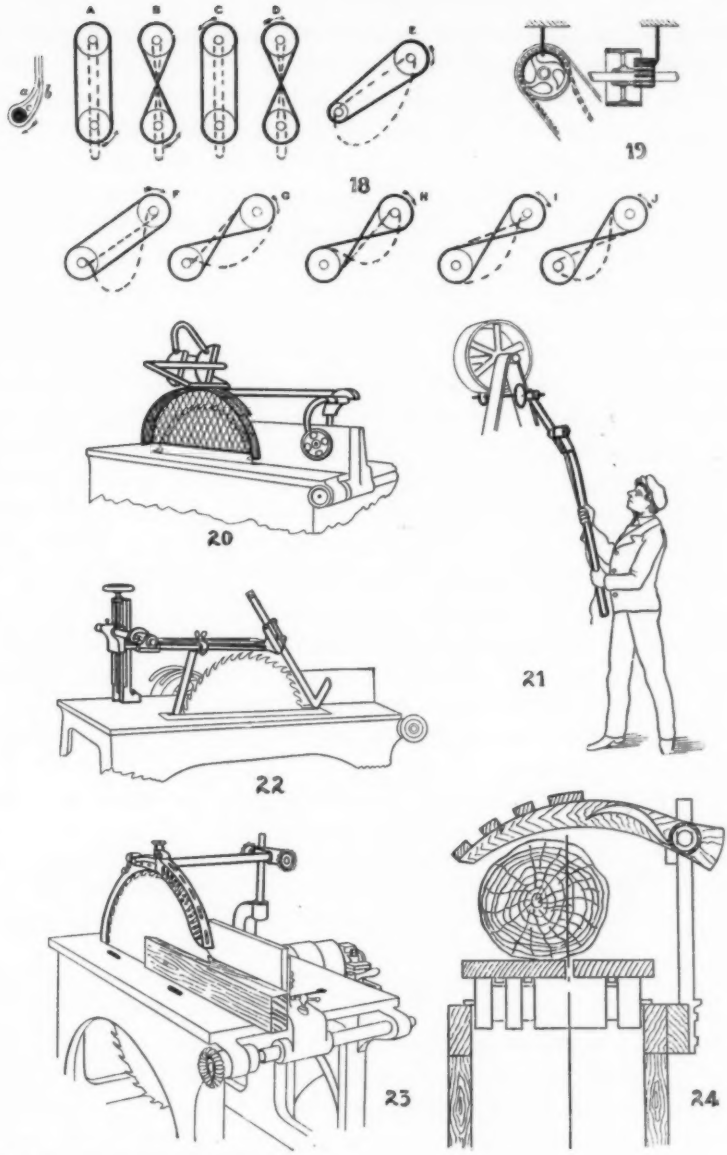


Fig. 18 Safe and Unsafe Idle Belts
Fig. 19 Belt Perch
Fig. 20 Automatic-Positioning Mesh Guard for Variable Diameter Converting Saw
Fig. 21 Belt Shipping Pole
Fig. 22 Automatic-Positioning Bar Guard for Variable Diameter Converting Saw
Fig. 23 Adjustable Shield Guard for Variable Diameter Converting Saw
Fig. 24 Spar Guard for Log Saw

paratus. These four, however, are probably the most prolific in accident to the operator when performing his usual duties. They comprise woodworking saws and cutters, punches and presses, rolling machinery of all kinds where handfeeding is necessary, and emery and other grinding wheels.

WOODWORKING SAWS

66 A close approach by the fingers of workmen to sharp cutting tools running at a very high rate of speed is essential in operating efficiently many woodworking saws and cutters. Consider first that king of accident producers, the common circular saw, which takes an annual toll of not a few lives. This tool, the author believes, mutilates several thousands of our workmen each year and renders many of these permanently unfit for following dextrous occupations.

67 It is the bête-noir alike of employers, employees, works executives, factory inspectors and casualty insurers. What contribution can the mechanical engineer make towards conservation in this instance? In spite of claims to the contrary such an article as a universal saw guard does not exist on the market. On the other hand, except in the case of small diameter checking and grooving saws covered by the work, the author believes it is quite possible to safeguard all saws to varying degrees conditioned by the uses to which they are put.

68 An efficient as well as a safe saw guard is one which may have to fulfil all or any of the following conditions:

a The safeguarding must be strongly made and once adjusted must be able to retain its position and form without special care on the part of the saw operator.

b It must so protect the saw, both above and below the bench and before and behind the saw that no one can accidently touch or fall upon the saw.

c It must not permit the work in a ripping saw to close upon the blade, mount the same or be projected to the danger of those around.

d It must not obscure the workman's vision of the line of the saw.

e It must be especially adapted to the class of work done on the saw bench and where required, it must leave all the area of the saw table clear of obstruction and also the space above the guard itself.

The ways in which these conditions for reducing saw accidents, while maintaining efficiency, have been met in the author's experience are illustrated in Fig. 20 and in Figs. 22 to 29 for various kinds of saws and applications of such, from the handling of the rough log to completely converted lumber.

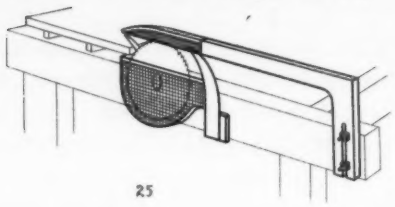
69 Fig. 28 shows in some detail the solution of a circular saw-protection problem where the conditions were supposed by workmen and foremen alike to forbid safeguarding which would permit the machines to be worked at full efficiency. The saw-bench illustrated is a combination trimmer and edger having three saws on one shaft.

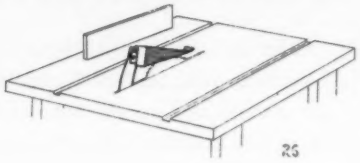
70 The over-hung saws, a rip and a cross-cut respectively, are fixed in position on the shaft ends but the middle cross-cutting saw must, with any guard, traverse the shaft freely when required for a distance of 18 in. The work handled varies from one to three thicknesses, totalling 2 in. and is fed into the saws on two sliding tables of 29-in. stroke and of fixed and variable gage respectively. Thus no attachment above the bench for any guard is possible at the front or sides or for about the above distance to the rear of the saw.

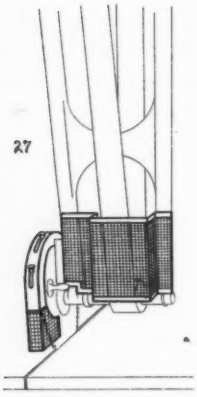
71 No purchaseable guard will meet such conditions. As finally worked out, the rip-saw has a safety parting-knife fitted in its rear, and all three saws are efficiently and strongly guarded, as shown, at every dangerous point. Men working at a rapid pace on task work at these benches are highly pleased with the result. They are able to use the three saws more effectively than before and without any fear of injury. The saw line is always visible through the mesh work and pierced work, yet the operators hands which necessarily travel with the work can never approach the saw teeth too closely, as they are pushed off by the projecting fingers.

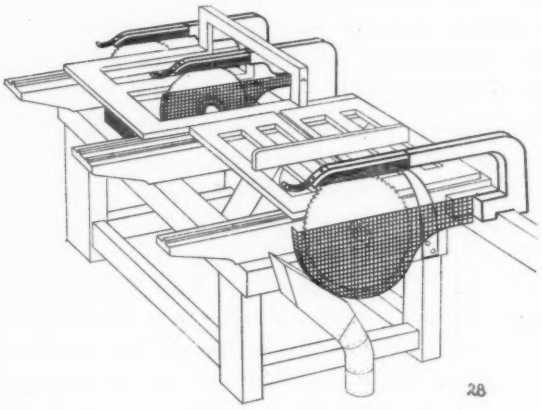
WOODWORKING CUTTERS

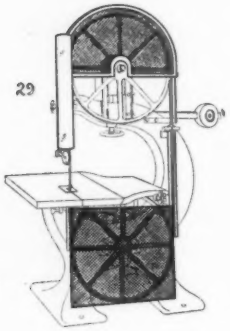
72 The common jointer accounts for a large number of finger and hand amputations every year and Figs. 30, 31 and 33 show three forms of effective guard. In the first and third, two movements, vertical and horizontal respectively, are necessary to adapt the guard to any given piece of work. In the second, the guard supported on springs rises automatically when pushed by the work and only the transverse sliding motion is necessary for positioning. After the work has passed the guard the latter returns automatically to a position close to the cutter gap. In the other two types the guards main-

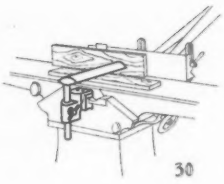


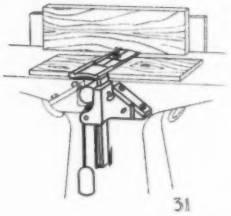












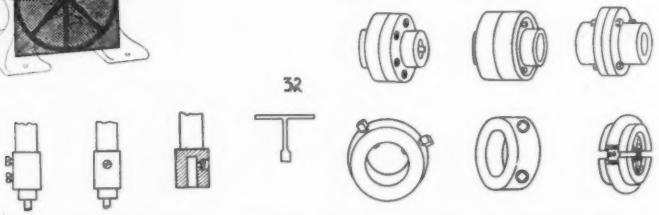


FIG. 25 MESH GUARD FOR CONSTANT DIAMETER OVERHUNG SAW REQUIRING CLEAR BENCH FOR SLIDING TABLE FEED

FIG. 26 MESH GUARD FOR CONSTANT DIAMETER SAW REQUIRING CLEAR BENCH FOR LUMBER

FIG. 27 ADJUSTABLE MESH GUARD FOR SWING SAW AND BELT

FIG. 28 GUARDED TRIPLE-SAW, SLIDE-FEED BENCH WITH CLEAR TABLES

FIG. 29 BAND SAW GUARDED AGAINST CONTACT AT ANY PART AND ALSO AGAINST SAW BREAKAGE

FIG. 30 ADJUSTABLE JOINTER GUARD

FIG. 31 TELESCOPIC JOINTER GUARD

FIG. 32 SAFE AND UNSAFE TRANSMISSION DETAILS: COUPLINGS, COLLARS AND SET SCREWS

tain their height above the table until readjusted. All these guards can be readily swung out of the way for cutter adjustments and as easily returned for use.

73 The vertical spindle molding cutters can also inflict serious injuries. Sometimes a leather knuckle-duster revolves with the tool and contact with it warns the workman of too close approach. Figs. 34, 35 and 36 show three forms of more positive safeguarding for this dangerous tool.

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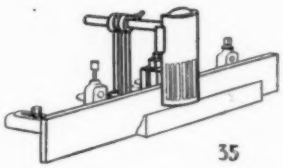

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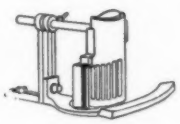

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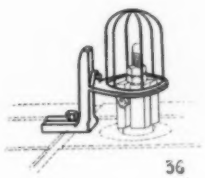

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FIG. 33 AUTOMATIC-POSITIONING JOINTER GUARD
FIG. 34 SPINDLE MOLDER SCREEN GUARD, THIN WORK
FIG. 35 SPINDLE MOLDER SCREEN GUARD, THICK WORK
FIG. 36 SPINDLE MOLDER CAGE GUARD

PUNCHES AND PRESSES

74 Punch and press machinery probably ranks next to woodworking tools in frequency of accident, though usually the operative escapes with less serious injury. The mechanical engineer cannot be too careful in seeing that these tools are in good repair, particularly the actuating gears. Automatic roll-feeds, sub-presses, magazine, hopper, gravity slides, Fig. 37, and push slides feeds, Fig. 40, have done a good deal to eliminate the dangers of feeding such pressess by hand but much work already blanked must still be handled in this way in subsequent punching and pressing operations.

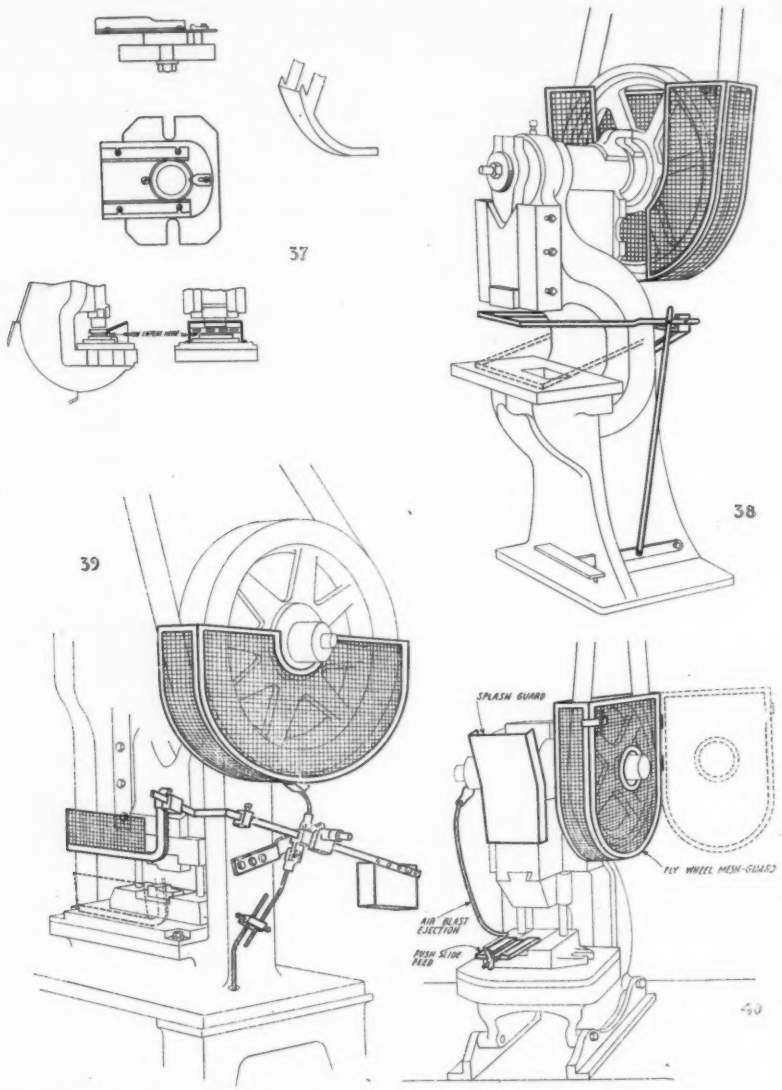


FIG. 37 GRAVITY SLIDE PRESS-FEEDS AND SCREENED PUNCH
FIG. 38 AUTOMATIC BAR GUARD FOR PRESS
FIG. 39 AUTOMATIC SCREEN GUARD FOR PRESS
FIG. 40 GUARDED FLYWHEEL, SPLASH GUARD, SLIDE FEED AND AIR-BLAST EJECTION ON BENCH PRESS

75 The increasing use of compressed air in mechanical industries permits of light pieces being blown off the die at the end of the operation by a cam-operated blast properly directed and timed, Fig. 40. The ordinary spring ejector serves the same purpose for heavier work. Yet there are many punches and presses running today without the efficient safeguards here illustrated and even where they are to be found the principles are not carried out consistently at all necessary places.

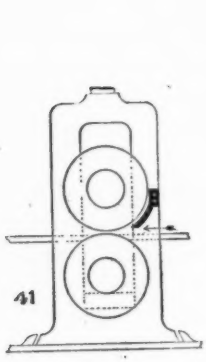
76 Fig. 40 is an example of a convenient flywheel guard, ordinarily locked in position, which the author arranged for a large series of small bench power presses worked by females. Provision is made in it for the tool setter having ready access for moving the flywheel by hand without detachment of the safeguard and resulting failure to replace it. The work in this machine is fed in by a push-slide and removed by a cam-actuated air blast. Figs. 38 and 39 show two forms of press guards, screen and bar respectively, which are timed to descend upon the operators fingers, if in a position of danger, and secure their withdrawal before an accident occurs.

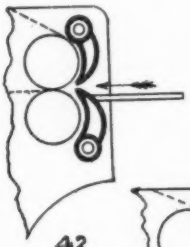
HAND-FED ROLLING AND GLAZING MACHINERY

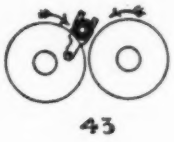
77 The third class of special apparatus essentially dangerous at the operating point is hand-fed rolling machinery of every description. A few of the safety suggestions which can be contributed by the mechanical engineer for this accident risk are illustrated in Figs. 41 to 46. At powerful hand-fed pressing and calendering rolls the injuries are usually very severe.

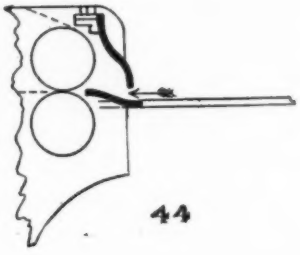
78 In the case of a single pair of large rolls such as are used for paper glazing, Fig. 41, comparatively thin sheets of material are fed in and it is possible by having the feed table level with the top of the lower roll and placing a bar, plate or screen across the bottom of the upper roll, to guard effectively the dangerous intake by arresting the operative's hand when accidentally traveling towards it on the work. Fig. 44 shows this plan applied to rolls used for burnishing sheet metals. In Fig. 42, hinged guards, preferably of mesh work, are used where the intake of the rolls must be at all times visible and instantly accessible. The fixed forms of roll guards, however, wherever possible, are the safest.

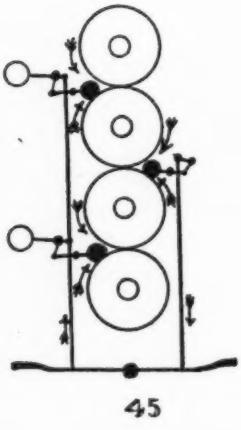
79 It is found in practice that the chance of accident from hand-fed vertical rolls is considerably reduced when a feeding table is used which keeps the operator at a safe minimum distance from the roll intake and











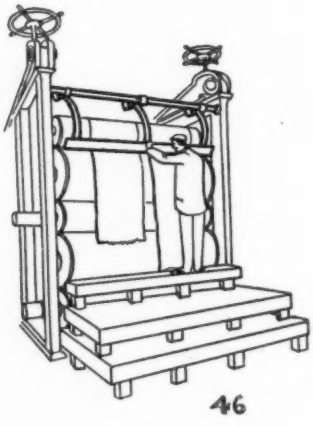


FIG. 41 GUARDED PAPER-GLAZING ROLLS
FIG. 42 HINGED METAL ROLL GUARDS
FIG. 43 LAUNDRY PRESS SAFETY ROLLER
FIG. 44 GUARDED METAL BURNISHING ROLLS
FIG. 45 CALENDERING MACHINE SAFETY ROLLERS
FIG. 46 CALENDERING MACHINE "STARTING IN" LEVER

necessitates a conscious effort to reach it. When rolls are operating on plastic materials, for example, in color mixing and baking machinery, easy access for cleaning and scraping the rolls is essential and a suitably placed rod attached to the top roll housing and rising and falling with it takes the place of the plate and mesh guards already illustrated.

80 In laundry and cloth finishing machinery such forms of protection are not practicable on the rolls owing to the nature of the work. To meet such cases a light, smooth auxiliary hardwood roll, Fig. 43, is substituted as a guard. It is pressed constantly against the main rolls by springs and is driven by them, but it fills the dangerous intake and arrests any part of the hand accidentally traveling towards the latter and in danger of being crushed.

81 In compound power-fed rolls with continuous webs of work such as heavy paper and cloth, calendering machines, multiple floating guard-rolls as above described, Fig. 45, can be used, controlled and released by a system of levers whenever a break in the web necessitates restarting by handfeeding. Fig. 46 shows a method of starting in by hand the feed of a cloth calendering or similar web-pressing machine. A counter-balanced bevel-edged board is used which ordinarily swings up and out of the way. With this the operator can with perfect safety push the cloth or other web home till it is gripped by the rolls.

EMERY AND OTHER GRINDING WHEELS

82 Emery wheels, grindstones and other abrasive tools when overspeeded or when strained or shocked while in motion within the limits prescribed by the makers, sometimes burst with great violence and spread death and serious injury in the path of their flight. Various methods for confining the wheel fragments to the machine casing or at least rendering their velocity harmless have been worked out and some of these are illustrated in Figs. 47 to 51. In all of them ample side clearance between the wheel and its casing is a primary requisite.

83 Fig. 47 shows the method of safely mounting the wheel and avoiding all initial stress due to wedging, keying and driving it into the spindle. Fig. 51 is the cone-sided wheel so shaped that fragments due to a fracture starting at the wheel center cannot escape beyond the washer plates. Figs. 49 and 50 show various forms of armoring successfully used to retain fractured wheels on disc and face grinders.

84 Fig. 48 is especially armored for large wheels subject to shock. It has hinged sides of plate steel and a strong cast-steel front guard also hinged. The guard as a whole can slide parallel to the plane of the wheel to take care of reducing diameter due to wheel wear and the hinged front guard can be dropped to meet the same condition. Wheels have been tested to destruction under all the guards illustrated without projecting fragments. Fig. 52 is a form of releasing

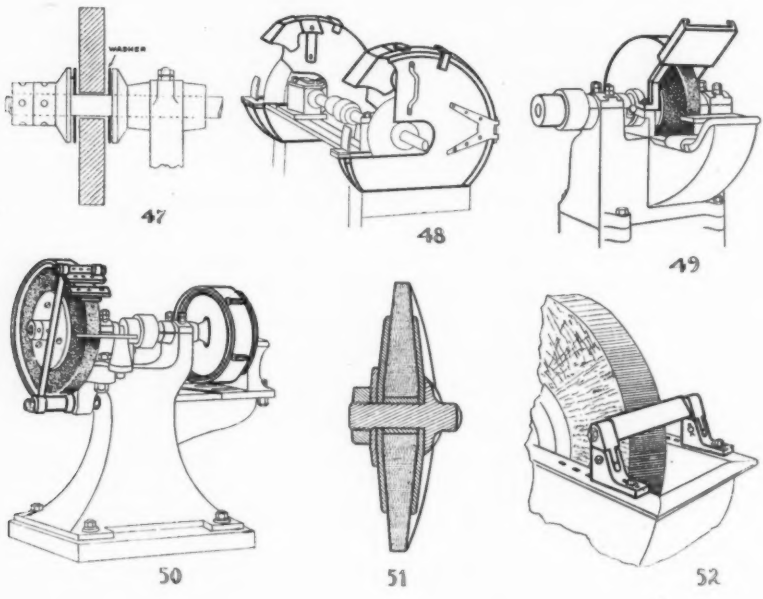


FIG. 47 SAFE MOUNTING OF GRINDING WHEEL
FIG. 48 ADJUSTABLE HEAVY ARMOR FOR DISC GRINDERS SUBJECT TO RAPID WEAR AND SHOCK
FIG. 49 SAFETY ADJUSTABLE HOOD FOR DISC GRINDER
FIG. 50 SAFETY ADJUSTABLE HOODS FOR DISC AND FACE GRINDERS
FIG. 51 SAFETY CONE-FORMED GRINDING WHEEL
FIG. 52 RELEASING GRINDSTONE REST

grindstone rest which prevents accidents due to tools catching between the usual fixed rest and the stone.

ESPECIALLY DANGEROUS PROCESSES

85 In addition to the wide scope afforded the mechanical engineer for assisting in the conservation of life and limb in the operation of

industrial machinery, there are not a few matters calling for his attention and for administrative regulation at various dangerous processes used in the arts. Chemical, electrical, metallurgical engineers and other industrial specialists have to reckon with risks to health, which, though not all strictly accidents in the sense we have so far been considering, will probably before long become charges upon industry.

86 Here also our aim as engineers and humane employers of labor should be primarily prevention. In concluding this paper, only passing notice can be taken of the wide field of dangerous processes where the machinery risk is sometimes absent and in safeguarding which the application of the training and experience of the mechanical engineer is essential to the best result.

EMPLOYMENT RISKS

87 In all our industries executives have to reckon closely with the varying degrees of responsibility which can be devolved on the young persons, women and male adults respectively who constitute our labor forces. It would help somewhat in accident prevention, and not a little in educational uplift, if in general hiring practice, no person of either sex under sixteen years of age was employed at or near machinery and if no employee whatsoever was allowed to clean machinery while in motion. The labor laws of the various States are more generous than this in the freedom permitted to employers.

88 Some of the existing restrictions are of doubtful constitutionality; and progress, meanwhile, is more likely to be made through voluntary enlightened action on the part of employers and other executives than by legal compulsion. In any case employment such as described may have serious civil consequences if it results in accident, and any employer is consulting important personal interests when he takes all possible steps to prevent dangerous employment about machinery and processes whether under statutory restriction or not.

RISKS DUE TO POSITION OF MACHINERY

89 The installation of machinery in relation to walls, passages, and adjacent tools and equipment deserves careful consideration from the mechanical engineer. In any confined space over which any person is liable to pass and towards which the carriage of any self-acting or automatic reciprocating machine runs out there should be

left a clear 18-in. passageway between the carriage when fully out and the wall or other fixed structure not part of the machine.

90 Danger due to position also arises in connection with limited clearance between other traveling or reciprocating machine parts and walls or fixed structures, as well as at the openings in the fixed machine framing which they pass. In large lithographic and printing machines the frame openings, often of considerable size, if left unguarded will frequently be used by the employees to store small personal articles. In reaching for these while the heavy table was in motion more than one person has been instantly killed.

91 Readily adjustable sheet metal door or wire screens such as are illustrated in Fig. 6 can easily be adapted to close up such openings, which are used to lighten frame castings, and end clearances of less than 18 in. should be effectively barred off from possible use as passages. Where the speed of the reciprocating part is considerable and a blow rather than a gentle push would be caused by accidental contact with it, the author recommends that the path of the piece be screened off permanently at the extreme end of its maximum working stroke.

STATIONARY EQUIPMENT RISKS

92 The protection by double rails of ordinary open stairs and gangways has already been referred to in discussing the causes of accident and the safeguarding of engines. Perhaps the most serious injuries in connection with fixed structures inside plants occur in chemical and bichromate works and in premises manufacturing paints, colors, oil, paper, soap, starch, sugar, etc., where large open receptacles for stock are in common use and the processes are necessarily continued day and night. These accidents arise from the absence at vats and pans, filled with boiling solutions or with liquors dangerous from their chemical nature, of some form of guard, rail or fence. Around these tanks and on or near their tops, in places often poorly lighted, men have to work. In most cases a double rail, 3 ft. high at least, is easily provided but difficult to keep in good repair, in many instances, in the oxidizing atmosphere of the processes.

93 The author has found the best arrangement to be that where the top 3 ft. of the vat or tank itself is used as a guard or fender and the working platform is this distance below the edge or lip of the dangerous vessel. Where boiling caustic or similar material is contained in the pans the provision of a counterbalanced dome-shaped cover which is ordinarily lowered by tackle over the pan prevents injuries to the

skin and eyes through projection of any dangerous material. Gangways over tanks and vats should be double railed on each side and their efficient maintenance closely watched. It is also well to round off the edges of open tanks or vessels, so that they offer no footholds.

94 Great practical difficulties surround the effective protection of workmen on temporary gangways, hatches and stages for the erection of which they are themselves sometimes wholly responsible. Such gang workers on bridge, shipbuilding and other large structural work and at docks will often fail to observe the most elementary precautions and cause many injuries to themselves and to others. Thus a gang of riveters or platers may erect a platform of merely one plank or two, but at intervals in the hull floor spacing a deep frame with plate stays occurs and in passing along rapidly the obstructed headroom is forgotten and a serious and often fatal fall is the result.

GASSING AND BURSTING RISKS

95 Gassing or the accidental inhalation of dangerous vapors is a source of accident in chemical works, gas works, gas storage plants, breweries, distilleries, etc., with fatal consequences sometimes where speedy rescue is lacking. Special means for efficient mechanical ventilation of such processes have to be devised by the engineer as well as close supervision and instruction of the semi-skilled labor found in such plants. The gassing risk, however, is not confined to such works. The upsetting, or accidental fracture of a carboy of acid in the pickling, plating or other room or store of any mechanical industry calls for quick and intelligent action.

96 One instance only will be cited of the striking ignorance still to be found among men long engaged in dangerous processes. A bricklayer who had been employed for fifteen years in a chemical works was called to repair a damaged stone-slab hydro-chloric acid tank in the open yard. On removing the earthenware cock some residual acid ran out on the ground and, without the least consciousness of danger, the workman threw a shovelful of plant wastes containing sulphides on the acid to absorb it and stepped upon the platform to repair the stone tank. Immediately deadly sulphuretted hydrogen was evolved below him from the mixture and gradually rose to the bricklayer's breathing level causing instant collapse and death. So little do operatives know or care to know about what is going on daily around

them that care should be taken to instruct them in elementary safety precautions and correct remedial treatment.

97 The ordinary explosion risks are well known and generally provided for in steam generators and other closed vessels under regulated pressure. In chemical and similar works, in the manufacture of dinitro-benzole and other explosives and in cartridge and shell filling the special risks call for the attention of the engineer, particularly in effective gas and dust removal and need not be detailed here. One class of explosive accident which is rarely fatal, but usually quite severe in its effects, particularly on the eyes, is the bursting of bottles in glass works under compressed air tests, and the explosion of bottles when being filled in plants with various aerated liquids. The painful lacerations and injuries caused in this way from projected glass fragments can be largely avoided by screening adjoining testing and bottling machines from each other and providing light wire-net masks, face-guards and veils and gauntlets for the arms and fingers of workmen handling bottles liable to burst.

Conclusion

98 In concluding this review of the field of industrial safeguarding in its more important manufacturing aspects and with special reference to its close relations to the art of the mechanical engineer, some administrative precautions should be briefly noticed.

DURABILITY AND IDENTIFICATION OF SAFEGUARDS

Safeguards, where at all possible, should be constructed of metal to secure durability. Reinforced steel mesh work is preferred by the author for all but the heaviest machinery. It is superior to guards of opaque material since it permits easy inspection without detaching the safeguard and interferes as little as possible with lighting conditions. In steel mills, foundries and heavy work plants of various descriptions, where the wear and tear of equipment is very great nothing but strong castings or steel plate work should be used for the majority of the guards. It is the practice of the author to have all safeguards readily distinguished by painting the body of them vermillion and the reinforced edges black. This allows executives to detect at a glance in going through the shops a displaced or defective guard, such parts being often small in area, in inconspicuous places, and liable to be overlooked.

WARNING AND CAUTION NOTICES

99 These should be sparingly used and as brief as possible. They give a possible legal protection from certain kinds of accident damage suits but they are practically worthless in every sense if no attempt is made to enforce them. The supervisory and educational efforts of fully instructed and sympathetic foremen receiving full credit for the safeworking of their respective departments and a few well-considered and enforced regulations prominently displayed in print are, the author believes, far more effective than a long catalogue of works rules which few will read and none will remember.

FIRST AID

100 It has been the practice of the author to give immediate and competent first-aid services within the plant to every injured person. The prompt cleaning and dressing of slight accidental wounds gives great relief to the sufferer and renders any later medical attention more effective. In the majority of cases nothing more is needed but neglected or delayed treatment of simple injuries may have most serious consequences.

ACCIDENT REGISTERS

101 Every works executive and engineer will find it a valuable adjunct to the safety engineering of the plant to maintain in every department, apart from labor law and casualty insurance reports, a full and accurate record of every accident and also of every near accident. Periodical examination of these and the determination of every mechanical engineer to practice safety engineering to the best of his ability, without regard to the legal minimum or compulsion, will help more than anything else to remove speedily a great reproach from our industrial life.

SPEED REGULATION IN HYDRO-ELECTRIC PLANTS

By Wm. F. Uhl

ABSTRACT OF PAPER

To obtain satisfactory speed regulation in a hydro-electric plant, it is usually insufficient to provide the turbine units with well designed governors.

Where the turbines are of the open flume type, and the velocity of approach does not exceed three to four feet per second, satisfactory regulation depends upon the fly-wheel effect of the rotating masses only, and the formula for calculating the speed variation is

$$d = \frac{800{,}000 \times \text{h.p.} \times \text{time}}{\text{r.p.m.} \times \text{r.p.m.} \times Wr^2}$$

Where encased turbines are employed, pressure variations occur which modify the results obtained from this formula. The ratio of the length of the turbine penstock to the head $\left(\frac{L}{H}\right)$, is a measure of the effect of these pressure variations. When this ratio is too great to obtain satisfactory results, the design of parts of the plant must be modified, or appurtenances such as pressure regulators and standpipes must be employed to reduce the pressure variations.

Tables are attached which give the pressure variations for various governor regulating times when the ratio $\left(\frac{L}{H}\right)$ and the penstock velocity are known.

SPEED REGULATION IN HYDRO-ELECTRIC PLANTS

WM. F. UHL,[1] BOSTON, MASS.

Non-Member

Although speed regulation of the turbine unit is one of the most important features in a successfully operating hydro-electric plant under modern conditions, it rarely receives more consideration in the design of a plant than to provide for the installation of a governor of some standard type.

2 The result is that a hydraulic turbine governor may be praised in one plant and condemned in another almost exactly similar, and the engineer contemplating such an installation often finds after the most thorough investigation that he can obtain recommendations and condemnations of every governor on the market.

3 The reason for this is invariably evident from an analysis of the various features of the plants regarding which information may be at hand, and of the original purpose for which any particular governor was designed.

4 Many plants where speed regulation has never received consideration operate under ideal conditions while other plants in which the conditions are not so good or are perhaps bad, have loads which are almost constant, and therefore practically no regulation is required. In these the most severe tests to which the governor is put, is to shut down the turbine in case of a short circuit and it is not surprising that good reports of governor operation are obtainable from engineers in charge of them. On the other hand, it often happens that governors are installed where the conditions for speed regulation are severe, or where the instantaneous or constant load changes are a large percent of the unit or plant capacity, and if the subject was not given proper

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consideration in the design of the plant, it is not surprising that bad reports are given of the same governors, which in the other plants are highly satisfactory.

5 In the present state of governor development, there is no reason why commercial regulation should not be obtained in every hydro-electric plant and even if not always equal to that obtained in modern steam plants, should at least be very nearly as satisfactory. This, however, can not always be accomplished by the installation of a well-designed governor alone, as the governor can perform only certain of the many functions which it is necessary to execute, no matter how perfect it is. In other words, it is necessary that the several parts of the whole hydro-electric plant be put in such relation that the governor, if properly designed, can perform the functions necessary for good commercial regulation.

6 If the plant has been arranged as above stated, very little difficulty will be experienced with any one of the governors put on the market by a number of reputable manufacturers in this country. There are cases, however, where the governor of one particular type or design may be more adaptable than the rest or some of the rest.

7 The sale of a governor is seldom left to the designer, who may know its limits and possibilities, and it is therefore important that the guarantee made by the manufacturer or his agent be carefully checked by the engineer designing the plant in which the governor is to be installed, even though the governor be the best on the market.

8 Some well-designed governors are in bad repute with some engineers, simply because the manufacturer or his agents were so eager to make a sale, that the question of adaptability, or the conditions under which the governor was to operate were overlooked, or if considered at all, the chance was gambled on that the plant would be an easy one to operate.

9 It is the purpose of this paper to give formulae by means of which the probable speed regulation can be computed for any set of conditions, and to make suggestions which may be helpful in arriving at a satisfactory proportioning of parts for good commercial results.

10 The regulation of hydro-electric units as now accomplished is one of degree only, since a departure from normal speed is necessary before the governor can act. Since the immediate effect of the gate motion is opposite to that intended, the speed will depart still further from the normal. This tends to cause the governor to move the gate too far, with the result that the speed will not only return to normal as soon as the inertia of the water and the rotating parts is

overcome, but may rush far beyond normal in the opposite direction. The obvious tendency is thus to cause the speed to oscillate above and below normal (hunting or racing) to the almost complete destruction of speed regulation.

11 A successful governor must therefore anticipate the effect of any gate movement. It must move the gate to, or only slightly beyond, the position which will give normal speed when readjustment to uniform flow in the flume or penstock has taken place. A governor with this property or quality is commonly said to be a "dead-beat" governor. The expedient used for this purpose on hydraulic governors is called a compensating device, which may be either simple or compound.

REGULATION OF OPEN-FLUME TURBINES

12 For the regulation of turbines in open flumes, where the velocity of approach does not exceed 2 to 3 ft. per sec., a gate movement only slightly increases or decreases the head, so that it may be considered that the immediate effect is the desired one, namely, to increase the flow of water for gate opening and decrease it for gate closing, so that the inertia of the water may be disregarded, consideration for the inertia of the rotating masses only being necessary. Thus in plants where turbines are used in open flume the danger of hunting or racing is practically eliminated, and by choosing the proper value for the rotating masses almost any desired speed regulation can be obtained. However, this is true only where the length of the draft tube is short compared with the head. The water in the draft tube must be accelerated or retarded at each change of gate opening and its kinetic energy changed at the expense of the power output in exactly the same manner as that in the penstock or flume. The effect is a tendency towards hunting or racing and it may be found that regulation with a governor is absolutely impossible at part load. In any case where a draft tube is used it must be included in all calculations. If the draft tube is long, and the velocity in it comparatively high, a quick closure of the turbine gates may cause the water in the draft tube to run away from the wheel, actually creating a vacuum, and then return again causing a destructive blow against the turbine. In such case, regulation of any kind is entirely out of the question.

13 From what has just been said, it is evident that with turbines in open flume, if there is a suitable velocity of approach in the flume and the draft tube is of proper dimensions, the regulation is a question of the inertia of the rotating masses of flywheel effect.

FLYWHEEL EFFECT

14 Flywheel effect is the capacity of a rotating mass to store or supply energy. This effect is expressed in pounds at 1-ft. radius, and is equal to the moment of inertia of a mass, that is, the weight by the square of the radius of gyration, or pounds feet squared. Modern alternating-current generator rotors are built in the shape of a common flywheel and usually have sufficient flywheel effect to obtain satisfactory regulation. The flywheel effect of the rotating parts of a turbine varies with different types and usually is not considered; but it should be carefully considered for large low-head multiplex and large diameter impulse turbines. In smaller turbines it may be regarded simply as introducing a factor of safety.

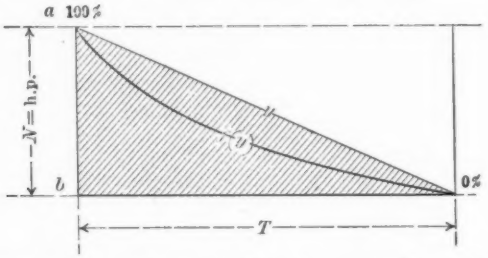


FIG. 1 ENERGY OF ROTATING MASSES GIVEN OUT IN TIME T

15 In turbines of very large diameter and in high-power reaction turbines, the weight of the water in the runner must also be considered to make the calculations of any value as its effect is exactly the same as that of any other rotating mass, and may be a large percentage of the total rotating mass. With geared turbines, the effect of all gears and shafting should be considered.

16 Where turbine-driven direct current exciters are used in a large hydro-electric plant, their possible regulation should be carefully considered, as the flywheel effect of these exciter generators is usually small and an additional separate flywheel may prove necessary.

17 When purchasing generators, a comparison of the flywheel effect should be made, as they are usually built as light and compact as possible. Additional flywheel effect within certain limits can usually be obtained at a very small cost in alternating-current generator rotors, and it will usually prove cheaper and more convenient to do this than to add a separate flywheel.

18 If a separate flywheel must be added, its weight for a given moment of inertia or flywheel effect depends upon the permissible

peripheral speed. In calculating a flywheel, the runaway speed (for full gate opening and friction load) must be considered and is really the determining factor. For an impulse turbine this runaway speed will be about 90 per cent above normal. For the standard types of reaction runners, *A*, *B*, *C*, *D*, *E*, and *F* (Table 1), the runaway speed will be respectively 70%, 65%, 60%, 55%, 50% and 45% above normal. These are the maximum speeds and they may be appreciably less, depending upon the setting of the turbine and the type of bearings used. For low speeds, flywheels of the engine type may be used, but for high speeds they should be of the disc type, turned all over and carefully balanced. The maximum peripheral speed for solid cast-iron disc wheels should not exceed 100 ft. per sec. and for cast-steel wheels of the same type, it should not exceed 200 ft. per sec.

19 Cast-steel wheels are usually more convenient on account of their smaller size for the same flywheel effect, and cheaper because less additional bearing surface is required, and the greater cost per pound of material, if any, is offset by the lighter weight, the flywheel effect varying with the square of the radius of gyration.

20 The regulation due to any given flywheel effect can be computed by means of the formula

$$d = \frac{800{,}000 \times N \times T}{n^2 \times Wr^2}$$

It must usually be modified, however, and to show clearly how this comes about, the derivation of this formula is given herewith, following which are given the symbols for the quantities used.

21 The energy of a rotating mass is $\frac{Mv^2}{2}$. If the peripheral velocity of the mass M is reduced from v_2 to v_1 it will lose energy amounting to

$$\frac{M\ (v_2^2 - v_1^2)}{2}$$

Factoring $(v_2^2 - v_1^2)$,

$$(v_2^2 - v_1^2) = (v_2 + v_1)\ (v_2 - v_1)$$

Substituting in the above and multiplying by $\frac{v}{v}$ we have

$$\text{Energy lost} = \frac{Mv\ (v_2 + v_1)}{2} \times \frac{(v_2 - v_1)}{v}$$

but

$$\frac{v_2 + v_1}{2} = \text{average velocity} = V$$

and

$$\frac{v_2 - v_1}{v} = \text{relative change in velocity} \equiv d$$

(d is also called the per cent of ununiformity).

22 Substituting the values of V and d in the above equation of energy lost, we have

$$\text{Energy lost} = Mvvd = Mv^2d$$

or

$$M \frac{(v_2^2 - v_1^2)}{2} = Mv^2d$$

23 Referring to diagram (Fig. 1), let ordinates represent horse-power and abscissae represent time. Then the energy, $\frac{NT}{2}$ is that which must represent the amount given out by the rotating masses, after the turbine gates have been closed off, and T is the time required to give it up. That is, if the total load is taken off suddenly, the power would drop from a to b, but on account of the rotating masses this would not happen instantaneously, but would take a certain time T, and the effect of the masses is equal to the area below the line y, and if this is a straight line the area $= \frac{NT}{2}$. Then

$$\frac{NT}{2} \times 550 = \frac{W}{g}\left(\frac{\pi^2 r^2 n^2 d \times 4}{60 \times 60}\right)$$

where

$$M = \frac{W}{g}$$

and

$$v = \frac{2\pi rn}{60}$$

Substituting numerical values and transposing, we have

$$Wr^2 = \frac{NT}{n^2 d}\left(\frac{60 \times 60 \times 32.2 \times 550}{2 \times 3.14 \times 3.14 \times 4}\right) = \frac{NT}{n^2 d}\ 800{,}000 \ldots\ldots [1]$$

and

$$T = \frac{Wr^2 n^2 d}{N \times 800{,}000} \ldots\ldots [2]$$

also

$$d = \frac{800{,}000 \times N \times T}{n^2 \times Wr^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [3]$$

which is the formula as first given, and

Wr^2 = moment of inertia of the rotating masses in lb. ft. squared

T = time in seconds to close or open gates by the governor

n = revolutions per minute

$$d = \frac{V_2 - V_1}{v} = \frac{n_2 - n_1}{n} = \text{the relative change of speed}$$

$$= \frac{(D\,w)}{w}$$

$$w = \frac{\pi n}{30} = \text{angular velocity}$$

N = horsepower

Correction. In deriving the above formula, it was assumed that the line y was a straight line and the area under it was equal to $\frac{NT}{2}$, under the assumption that the total load was thrown off.

24 However, the friction load of the turbine and generator remains, and the actual area represented will be that under a curve $f(y)$. The effect of this friction load will, of course, be different depending upon the various types of turbines used, but the original formula may be modified safely as follows, the curve $f(y)$ being approximately a parabola:

$$d' = 0.8\,d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [4]$$

25 Another cause which should be taken into consideration, providing the turbine is properly designed so as to give its maximum efficiency at normal or synchronous speed, is that the efficiency is reduced with either increasing or decreasing speed, which has the tendency to reduce still further the area under the curve $f(y)$. The amount reduced varies with the type of runner, being greatest for a high-speed, high-power runner, and least for a low-speed, low-power runner, since, if correctly designed and therefore following the laws of hydraulics, the change in efficiency will be greater for a high-speed than

for a low-speed runner for the same per cent of variation in speed. The formula modifying d' for this cause, is as follows:

$$d_{\text{eff}} = \frac{d'}{1 + \frac{d'}{\frac{n_1}{n_0} - 1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [5]$$

where $\frac{n_1}{n_0}$ varies from 1.8 for a runner of low speed to 1.3 for a runner of high speed.

26 Referring to the table of standard runners types A to F (Table 1, see end of paper), designed under the writer's direction for the Allis-Chalmers Company, the values of $\frac{n_1}{n_0}$ are as follows:

Type of Runner.....	A	B	C	D	E	F
Value of $\frac{n_1}{n_0}$	1.8	1.7	1.6	1.5	1.4	1.3
Specific speed $k = \frac{\text{r.p.m.}}{H}\sqrt{\frac{\text{h.p.}}{\sqrt{H}}}$	13.55	20.3	29.4	40.7	$\frac{49.7}{62.8}$	$\frac{70.97}{83.78}$

27 The specific speed is that speed in revolutions per minute of a turbine runner, diminished in all dimensions to such an extent as to develop 1 h.p. when working under the head $H = 1$ ft. This value is called type characteristic by Professor Zowski in his article in the Michigan Technic of June, 1908, The American High Speed Runners for Water Turbines.

28 To simplify calculations, this table will prove efficient:

Type of Runner....	A	B	C	D	E	F
$0.8x$ in $d_{\text{eff}} = 0.8x\ d$	0.714	0.703	0.69	0.671	0.645	0.606

29 For impulse turbines the same d_{eff} as for type A reaction runner should be used.

30 To find the speed variation for any other than a full load change, the following must be considered: If T is the regulating time for the total governor stroke or 100 per cent load of the turbine, it would appear that for 50 per cent load or stroke, the regulating time would be $\frac{T}{2}$, and for 25 per cent, $\frac{T}{4}$, etc.

31 As far as the stroke is concerned, this is nearly true with a mechanical governor, and the speed variations for part load changes can be calculated as follows:

32 The formula for d which we have given, may be transformed to appear:

$$d = \frac{Z^2}{2\left[\frac{2\left(\frac{mv^2}{2}\right)}{550\ NT}\right]}\left[1 - \frac{2\ aZ}{3\left[\frac{2\left(\frac{mv^2}{2}\right)}{550\ NT}\right]}\right]$$

33 In which the new symbols Z and a are, respectively, the change in load, and the remaining load.

34 If we let

$$S = \frac{1}{2\left[\frac{2\left(\frac{mv^2}{2}\right)}{550\ NT}\right]}$$

in the foregoing formula, it will appear as follows:

$$d = SZ^2\left(1 - S\frac{4\ aZ}{3}\right) \ldots\ldots\ldots\ldots\ldots\ldots [7]$$

35 From this formula, we can now compute d for various part loads, since S, as may be readily seen, is d as figured from the original formula for total change of load, or $S = d'_{\text{eff}}$ in the above formula, and for load changes of 25%, 50% and 75% we have the following:

a For 25%, $Z = 0.25$ and $a = 0.75$
$d'\ 25\% = d'_{\text{eff}} \times 0.625\ (1 - d_{\text{eff}} \times 0.25)$

b For 50%, $Z = 0.50$ and $a = 0.50$
$d'\ 50\% = d'_{\text{eff}} \times 0.25\ \ (1 - d'_{\text{eff}} \times 0.333)$

c For 75%, $Z = 0.75$ and $a = 0.25$
$d'\ 75\% = d'_{\text{eff}} \times 0.56\ (1 - d'_{\text{eff}} \times 0.25)$

36 The results of these computations plotted appear as in Fig. 2, in the line marked *a*.

37 Line *a* correctly represents the speed variation under the assumption that the governor acts instantaneously upon a speed change;

however, a certain speed change must occur before the governor can act on account of the insensitiveness of the flyballs, and the actual speed changes are more correctly represented by a line *b*, midway between the curve *a*, and a straight line *c*, as shown.

REGULATION WITH HYDRAULIC GOVERNORS

38 For a hydraulic governor, an entirely different line of reasoning must be followed. My own observations are supported by those of others who claim that the regulating time for all gate openings is nearly constant and equal to that of the total gate opening for a hydraulic governor.

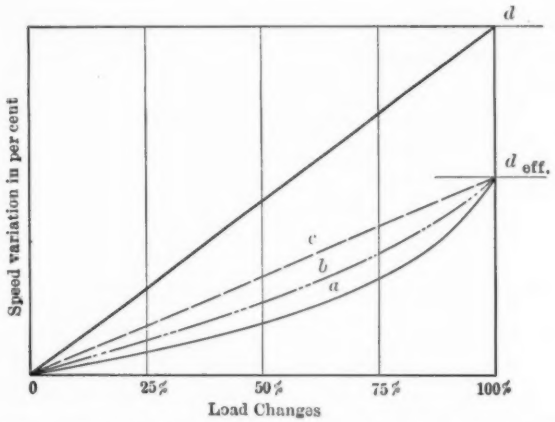


FIG. 2 APPARENT AND ACTUAL REGULATION OF MECHANICAL GOVERNOR

39 This is due largely to the throttling effect of the regulating valve and the time required to overcome the inertia of the regulating masses. That this fact is not detrimental to the speed regulation can be seen from what follows, and that it is of large benefit to the problem of pressure variations and therefore indirectly again to regulation, will be seen from a study of the following discussion on pressure variations.

40 From experience and tests, it has been found that for hydraulic governors the curve *a*, shown under partial load speed variation for mechanical governors, must be modified as shown in Fig 3.

41 The curve *d* is an arc of a circle drawn tangent to the line *od* which is the line of apparent regulation, and through the point d_{eff} which is the actual value of d' as modified for various causes as given.

42 It would appear from a comparison of the regulation curves

given that the speed variation would be less for partial loads with the mechanical governor than with the hydraulic governor. This, however, is not true for practical purposes, since the regulating time for any but very small mechanical governors is, of necessity, very great compared with the hydraulic governor, the regulating time of which can practically be made as short as desired for any size. From an investigation of the original formula for d, it can be seen that d varies directly with T, and therefore, if we can use a shorter time T, with the hydraulic governor than with the mechanical, it is seen that the apparent advantage can be overcome many times, due to the very short time T, possible.

43 A mechanical governor can perform only a definite amount of work per unit of time, depending upon the size and strength of the

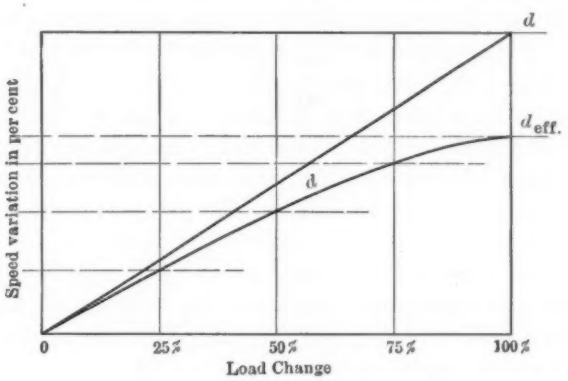


FIG. 3 APPARENT AND ACTUAL REGULATION OF HYDRAULIC GOVERNORS

driving belt or gears which must transmit the power of the governor. If for instance, a mechanical governor is capable, due to the strength of its parts, to transmit 1 h.p. = 550 ft. lb. per sec., and the work required to regulate a turbine is 11,000 ft. lb., then the regulating time must be $\frac{11{,}000}{550} = 20$ sec.

44 The work which a hydraulic governor is capable of doing, is a question of the size of the regulating cylinder, and the time in which it can do this work depends upon the time in which sufficient oil can be brought to the cylinder. This time again depends upon the pressure in the pressure tank and the size and discharge coefficient of the oil pipes and the regulating valve.

REGULATION OF ENCASED TURBINES

45 If the water is conducted to the turbine in a long penstock (encased turbine) a large amount of energy is stored in the moving column of water and a change in its velocity involves a change in its kinetic energy and produces pressure variations, which may, if an attempt is made at too rapid regulation, leave the turbine deficient in energy when increased power is desired, or when the power is decreased, may produce such shocks as will seriously affect regulation, or perhaps result in serious injury to the penstock or turbine.

PRESSURE VARIATIONS

46 With open-flume turbines, these pressure variations may be disregarded, but with encased turbines they must always be carefully considered. These variations can never be done away with entirely in practical cases, but they can be minimized to almost any extent by proportioning properly the various parts of a plant. The solution of such a problem is generally determined by commercial considerations, and a balance must be struck between cost of penstocks and cost of flywheels, if it is impossible or undesirable to modify conditions with other appurtenances.

47 Pressure variations to a greater or less extent, occur in every practical turbine installation, whenever the amount of water which flows to the turbine is varied, as in the case of a change of load. However, for practical considerations, as far as regulation of speed with governors is concerned, these variations can be considerable before they will have any appreciable effect on the speed regulation. In modern plants, where the tendency usually is to develop as much power and head as possible in a single plant, it frequently becomes necessary to carry the water for some distance in flumes, pipe lines or tunnels in order to concentrate the head on the plant. The length of the conduits often becomes many times greater than the head, and as such long conduits become a large factor in the cost of the plant, the natural tendency is to reduce the size of conduit and increase the velocity of the water flowing in or through it. However, head, length of conduit, and velocity of water in the conduit, are the three principal factors that produce pressure variations, and their relation to each other, as well as their effect on regulation of speed, becomes a very important problem in such plants.

48 In such a plant, the effect of the flywheel masses is the same as before, and the same theory and formulae apply to it. However,

instead of a constant head acting on the turbine, we will have a variable head, which may become greater or less than the normal, depending upon the change of load. This variation in head tends to increase or decrease the amount of power which would be developed for the same gate opening at normal or constant head, and the tendency of the flywheel effect to keep the speed constant is lessened by the amount of increased or deficient power so caused.

49 As calculated from the foregoing formula, "d effective" must be modified by the following formulae due to the causes above mentioned.

For closing gates

$$d''' = d_{\text{eff}}\left(1 + \frac{(D\,H)}{H}\right)^{\frac{3}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [8]$$

For opening gates

$$d''' = \frac{d_{\text{eff}}}{\left(1 - \frac{(D\,H)}{H}\right)^{\frac{3}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [9]$$

The derivation of these formulae and the theory leading up to them are herewith given.

50 We know, from the fundamental axioms of mathematical physics, that a given mass acted upon by a variable force in an interval of time is accelerated or decelerated. This relation is given by the following fundamental equation

$$M\frac{\mathrm{d}v}{\mathrm{d}t} = P$$

and

$$M\mathrm{d}v = P\mathrm{d}t$$

51 In the problem relating to speed regulation we always deal with a fixed time T, and a variation in the velocity of the water brought about in the time T, which is identical with a pressure variation. We may, therefore, write

$$M\,(Dv) = (DP)\,t$$

where

$$M = \text{mass} = \frac{W}{g}$$

in which

W = weight in lb.

$g = 32.2$ = acceleration of gravity

and

P = pressure = Hy

in which

$\frac{P}{y} = (DH)$, where y = specific weight

Let L represent the length of a pipe line or penstock and F its area. Then

$$M = \frac{LFy}{g}$$

$$P = FP = Fy\,(DH)$$

And substituting in the equation $M(Dv) = (DP)t$, we have

$$\frac{LFy}{g}(Dv) = Fy\ (DH)T$$

Transposing

$$(DH) = \frac{L(Dv)}{gT} \quad \ldots\ldots\ldots\ldots\ldots\ldots [10]$$

or the actual increase or decrease of head for certain regulating time T, and a variation of the velocity of the water of (Dv).

52 This formula, to express the result in per cent of the total head, will read

$$\frac{(DH)}{H} = \frac{L(Dv)}{gTH} \quad \ldots\ldots\ldots\ldots\ldots\ldots [11]$$

and for both increase and decrease it will read

$$\frac{(DH)}{H} = \pm \frac{L(Dv)}{HgT} \quad \ldots\ldots\ldots\ldots\ldots\ldots [12]$$

where $+$ is for closing and $-$ is for opening gates.

53 From this formula we learn that the pressure variations vary directly with the length of the penstock and the velocity of the water in it, and inversely as the head and the time during which the original velocity is varied by (Dv).

54 If we assume an allowable pressure variation, $\frac{(DH)}{H}$, the regulating time can be found from a transposition of the above formula, as follows:

$$T = \pm \frac{L(Dv)}{Hg\frac{(D\,H)}{H}} \qquad [13]$$

As an example, let

$L = 500$ ft.
$H = 100$ ft.
$V_0 = 100$ ft per sec. for $T = O$
$v_1 = 5$ ft. per sec. for $T = 2$ sec.
$(Dv) = v_0 - v_1 = 5$ ft. per sec.

Then

$$\frac{(DH)}{H} = \pm \frac{500 \times 5}{100 \times 32.2 \times 5} = \pm 0.39 = \pm 39\%$$

which shows that for a change in penstock velocity of 5 ft. per sec. the pressure would increase or decrease 39 %.

55 Where a pressure variation not to exceed 10% is permissible, $\frac{(D\,H)}{H} = 0.10$, and the corresponding regulating time for the same conditions must be

$$T = \pm \frac{500 \times 5}{100 \times 32.2 \times 0.10} = 7.8 \text{ sec.}$$

which shows that it takes 7.8 sec. to accelerate or decelerate the velocity by 5 ft. in order not to increase or decrease the pressure to exceed 10 %.

56 As may readily be noted, the above formula gives equal results for increase or decrease of pressure, and both values become infinity if any of the factors in it become infinity or zero. It is impossible, however, to imagine the pressure decrease to become infinity; it is evident that the decrease can never exceed 100% and if this limit is surpassed, or even reached, the liquid column must sustain a rupture, and the water will flow intermittently or in the form of pulsations. From this it is evident that the formula can be correct

only, if at all, within certain limits and under certain restrictions, and then only approximately, as we will see from our further discussion.

57 The above indicates that we must analyze this problem further in order to get formulae which will cover the ground and give more exact results.

58 It is a well-known fact that if penstock conditions are disturbed by moving a gate anywhere in the line, either at the upper or lower end or intermediately, the whole system becomes oscillatory, which means that the pressure and velocity in the penstock are oscillating.

59 A similar phenomenon can also be experienced in an open flume in which water is flowing. Assume that the gate at the lower end of such a flume is closed. A wave will be produced next to the gate, and this will proceed upward along the flume with a certain velocity, until it disappears either in the intake basin, where v nearly equals zero, or it will be dissipated by friction on the flume walls, depending upon the length and roughness of the flume and the velocity of the wave.

60 In closed flumes or penstocks, such waves do not disappear so quickly, the surface friction being small in comparison with the velocity and the produced force, and its influence may even be neglected.

61 It is evident that these waves, or rather vibrations, are liable to interfere with each other and consequently affect the pressure in the penstock. It is therefore of greatest importance to determine the velocity with which these vibrations travel in and along the penstock.

VELOCITY OF VIBRATIONS

62 This velocity of the vibrations, which we will indicate by C in our further discussion, depends (a) upon the compressibility of the liquid, and (b) upon the nature of the material of which the penstock consists.

63 It is a well known fact that vibrations in water proceed with the same velocity as does sound, and if the walls of the flume or penstock can be considered absolutely rigid, C therefore depending only upon the compressibility of the water, the velocity of the vibrations will be 4650 ft. per sec., or, as already stated, the same as that of sound. The penstock walls, however, are always flexible to a certain degree, depending upon the elasticity of the material from which they are constructed, and therefore they also exert a certain influence upon the vibrations.

64 Under the influence of pressure variations, the penstock walls, due to their property of elasticity, expand and contract in a rather remarkable degree, called "breathing" of penstocks. Due to this breathing, the velocity of vibration is reduced, the motion so produced naturally having a damping effect upon the vibrations, the same as any other obstruction would have. The velocity of 4650 ft. per sec. may therefore be considered a maximum with which any vibrations in the penstock will proceed.

65 The actual velocity of the vibrations can be computed by means of the following formula:

$$a = \sqrt{\frac{\frac{g}{y}}{\frac{1}{e} \times \frac{1}{E} \times \frac{D}{d}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [14]$$

where

g = acc. of gravity = 32.2 ft. sec.^{2}

y = specific weight of water = 62.4 lb. ft.^{3}

$\frac{1}{e}$ = elasticity of the water, e = 42,000,000 lb. ft.^{2}

$\frac{1}{E}$ = elasticity of penstock material in lb. ft.^{2}

D = diameter of penstock in ft.

d = thickness of penstock wall in ft.

66 The value of E is variable for the same material and for different materials. The following average values have been taken from Kent's Mechanical Engineer's Pocket Book and from the German engineer's hand-book Hütte.

For steel plate, E = 28,000,000 lb. in.^{2} = 4.032.10^9 lb. ft.^{2}

For cast iron, E = 15,000,000 lb. in.^{2} = 2.16.10^9 lb. ft.^{2}

For wooden staves, E = 1,680,000 lb. in.^{2} = 2.42.10^8 lb. ft.^{2}

67 If we substitute the numerical values for g, y, and e, in formula [14] and, for the sake of brevity, place the letter $K = E^{-1} \times 10^{10}$ we will obtain

$$a = \frac{22{,}720}{\sqrt{23.5 - K \times \frac{D}{d}}} \quad \ldots\ldots\ldots\ldots\ldots [15]$$

68 The value of K can now be computed for the various penstock materials, and will be as follows:

Steel plates, K = 0.232

Cast iron, K = 0.464

Wooden staves, K = 41.50

69 Formula [14] was first derived by Lorenzo Allievi, C.E., of Rome, Italy, and published by him in 1903 in the Italian paper, Annali della Società degli Ingeneri ed Architetti, under the title Teoria a generale del moto perturbato dell' acqua nei tubi in pressione. In 1904, this article was translated into French under the title Théorie générale du mouvement varié de l'eau dans les tuyaux de conduite, in the French paper Revue de Mécanique.

70 Based on the foregoing formula and values for K, Table 8 (see end of paper), giving values of a, has been computed, and includes diameters of pipes from 1 ft. to 20 ft. with thickness of walls from $\frac{1}{4}$ in. to 5 in.

71 For practical use, at least for preliminary purposes, or when the table is not at hand, the value of a can be taken as 3300 ft. per sec. for customary diameters and thicknesses of penstocks.

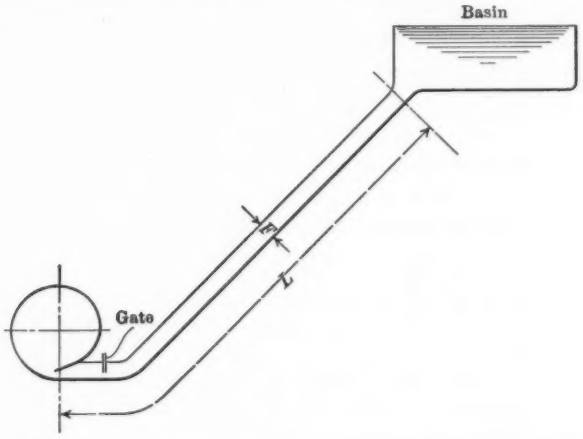


FIG. 4 PENSTOCK CONDITIONS RESULTING IN PRESSURE VARIATION

72 The effect of the velocity of vibrations upon the pressure variations depends upon the regulating time T, as will be seen from the following discussion.

73 If we assume a penstock of length L, as shown in Fig. 4, with a basin at its upper end and a gate at the turbine, the water with the gate open will have a velocity v. If the gate is closed, we have a variation in the velocity, with corresponding pressure variations and vibrations. As shown above, the vibrations will travel along the pipe line with a velocity a, and will reach the basin in a time, $t = \frac{L}{a}$. If the basin is sufficiently large, that is, if its area is many times that of the penstock, then the hydro-dynamic reaction, due to the large body

of water, is the cause of a new series of vibrations which proceed down the penstock with the same velocity a, as before, and the gate is again reached by them in the time, $t = \frac{2L}{a}$.

74 These reproduced waves coming from the basin will interfere with the waves traveling upwards and have the tendency to diminish the resulting pressure variations in all sections of the penstock, therefore also those in the gate area. This would indicate the following:

a Up to the time $t = \frac{2L}{a}$ $\left(\text{period } t = o \text{ to } t = \frac{2L}{a}\right)$, the pressure in the gate area is constantly increasing as if the penstock were indefinitely long. (See Fig. 5.)

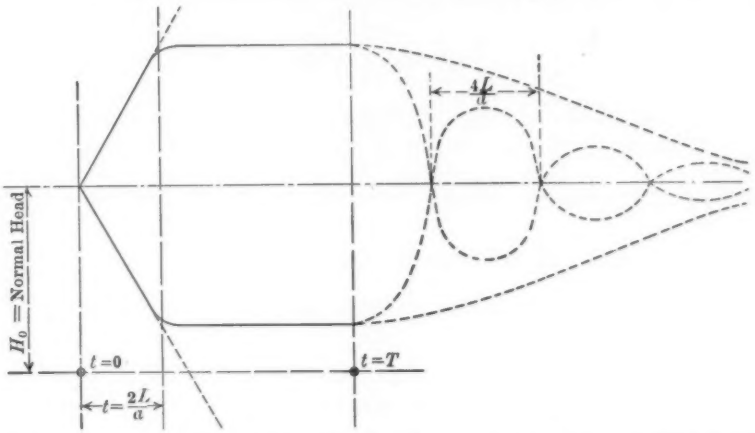


FIG. 5. EFFECT OF TIME DURING WHICH A CHANGE IN PENSTOCK CONDITIONS IS AFFECTED

b Starting from the moment $t = \frac{2L}{a}$ the pressure variations are weakened by the retroceding waves or vibrations, and we conclude that the pressure must rest constant from the time $t = \frac{2L}{a}$ until the gate stops in its travel, $(t = T)$, as both series of vibrations have an equal effect on the pressure.

c When the gate is stopped in its travel, $(t = T)$ we get different conditions depending upon whether it is fully or partially closed. If it is fully closed, fluctuations will occur having a period of $\frac{4L}{a}$, but these will become smaller and smaller until the original pressure is reached.

75 If the gate area is only partially closed in the time $t = T$, the pressure rise will decrease asymptotically, since the column of water still keeps moving, but with a changing velocity.

76 Only the period from $t = o$ to $t = \frac{2L}{a}$ will be of interest to us in this discussion, since during this the maximum pressure rise or drop occurs.

77 The graphical illustration given in Fig. 5 explains our reasoning more clearly. From the point $t = o$ to $t = \frac{2L}{a}$, the pressure is constantly increasing or decreasing. From the point $t = \frac{2L}{a}$ to $t = T$ the pressure remains constant.

CRITICAL TIME

78 From the above, we see at once that it would be working against desired results should we choose a regulating time T for a governor less than the value $\frac{2L}{a}$, without awaiting the weakening effect of the reflected waves which arrive at the gate in the time $\frac{2L}{a}$.

79 Therefore, the governor regulating time T should always be greater than the time $t = \frac{2L}{a}$.

80 To show this fact just stated more clearly, we will consider both cases:

$$(a) \quad T < \frac{2L}{a}$$

and

$$(b) \quad T > \frac{2L}{a}$$

81 As we have already shown, if the gate is closed in a time $< \frac{2L}{a}$, the pressure rises as long as the gate is kept moving, and if the gate is totally closed, we will obtain the maximum possible pressure obtainable in a penstock.

82 This maximum pressure can be computed by means of the formula:

$$H_{max} = H_o + \frac{av}{g} \quad \ldots\ldots\ldots\ldots\ldots\ldots [16]$$

where

H_0 = initial head
v = velocity in the penstock
g = acceleration of gravity

83 This formula shows us that every change in velocity of 1 ft. means an increase or decrease in head of

$$\frac{a \times 1}{g} = \frac{3300 \times 1}{32.2}$$

$$= \text{about } 100 \text{ ft. if } T < \frac{2L}{a}$$

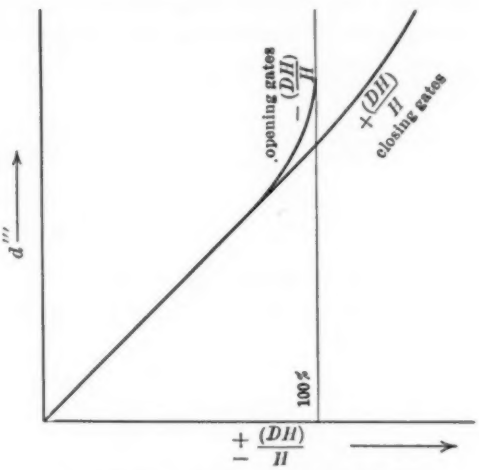


FIG. 6 LIMIT OF PRESSURE VARIATIONS

84 From the example which we have considered under formula [13] we have

$$v_0 - v_1 = 5 \text{ ft.}; H = 100 \text{ ft.}; L = 500 \text{ ft.}$$

$$T = \frac{2L}{a} = \frac{2 \times 500}{3300} = 0.3 \text{ sec.}$$

$$H_{max} = 100 + \frac{3300 \times 5}{32.2} = 600 \text{ ft.}$$

which indicates that the pressure would rise from 100 ft. to 600 ft. if we closed the gate completely in the time $t = \frac{2L}{a} = 0.3$ sec.

85 The time $t = \frac{2L}{a}$, therefore, represents a *critical time*, which

should always be calculated, and the governor regulating time chosen as much greater as other conditions will permit.

86 If we now compare formula [10] originally derived for a maximum pressure rise, with formula [16] we obtain a difference for H_{max} as follows:

From formula [10]

$$\frac{(DH)}{H} = \frac{500 \times 5}{100 \times 32.2 \times 0.3} = \text{about } 2.6 = 260\%$$

$$(DH) = 260 \text{ ft.}$$

$$H_{max} = 100 + 260 = 360 \text{ ft.}$$

as compared with 600 ft. as obtained from formula [16]. This clearly illustrates the importance of considering the effect of the vibrations and elasticity of the water as well as the elasticity of the penstock walls.

87 It is evident that the theory by means of which formula [16] is derived, shows the maximum value of H, as for the period

$$t = o \text{ to } t = \frac{2L}{a} \text{ or } \left(T \overset{=}{<} \frac{2L}{a} \right)$$

it is immaterial in what time the kinetic energy is stored in the penstock. If we close the gate completely, the same energy is stored up, whether the gate is closed in 0.1 sec. or 0.3 sec.

88 As has already been shown, for a closing time, $T > \frac{2L}{a}$, the pressure rise is constant, and this constant pressure increase or decrease represents the maximum possible value for such a regulating time, and may be calculated by means of the following formula:

$$\frac{(DH)}{H} = \frac{n}{2}\left(n \pm \sqrt{n^2 + 4}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots [17]$$

true for the period

$$t = \frac{2L}{a} \text{ to } t = T$$

where

$$\frac{DH}{H} = \text{pressure variation}$$

$$\frac{DH}{H} \times 100 = \text{pressure variation in per cent}$$

$$n = \frac{Lv}{gHT} = \text{formula} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [10]$$

Use + sign for closing gates and − sign for opening gates.

89 This formula [17] is most important in our calculations, since it gives us the momentary head under which a turbine must operate during a load change for any given regulating time.

90 The results of this formula plotted graphically give us two curves one for increase of head and one for decrease of head. For an increase, if n = infinity, $\frac{(DH)}{H}$ = infinity; for a decrease, if n = infinity, $\frac{(DH)}{H}$ will asymptotically reach the value 1. (See Fig. 6.)

91 It will be noted that formula [17] contains just those factors which we missed in formula [10]. According to formula [10], our results, if plotted, would appear along the straight line as shown, practically midway between the two curves, $+\frac{(DH)}{H}$ and $-\frac{(DH)}{H}$. (See Fig. 7.)

92 We note further that for a regulating time greater than $\frac{2L}{a}$ and variations of pressure not exceeding 20 to 25%, formula [10] may be used approximately. For larger variations, the difference between $+\frac{(DH)}{H}$ and $-\frac{(DH)}{H}$ becomes considerable, and formula [17] must be used even for approximate results.

93 Tables 3 to 8 (See end of paper) have been computed from formula [17] and are based on different values of $\frac{L}{H}$, (where L is the length of the penstock and H the effective head), and for velocities up to 20 ft., each table giving the pressure variations both $+\frac{(DH)}{H}$ and $-\frac{(DH)}{H}$ for a given regulating time T.

94 These tables will be found of great benefit in determining quickly the regulating time and the corresponding pressure variations for different penstock diameters, providing L and H are given, as they are in practically every case. But, in determining or assuming the regulating time, it must be remembered that it must always be greater than $\frac{2L}{a}$.

95 Referring to the tables and the case already used to illustrate, namely, L = 500 ft., H = 100 ft., v = 5 ft. and T = 2 sec.

$$\frac{L}{H} = \frac{500}{100} = 5$$

$$\frac{(DH)}{H} = +0.471 \text{ and } -0.32 = 47.1 \text{ and } 32 \text{ per cent}$$

From formula [10] we would obtain

$$\frac{(DH)}{H} = 39 \text{ per cent}$$

as the approximate average value of the exact results. The tables permit of interpolation.

96 It now becomes necessary to analyze the effect of the pressure variations on the speed regulation.

97 As already stated, if the regulating time, T is chosen greater than $\frac{2L}{a}$ the pressure rise or drop, and therefore the head remains constant and its maximum value may be calculated from formula [17], according to which the tabular values are found. We may therefore, assume that the turbine is operated at a constant head during any load change, the head varying for different per cent of changes; and the head for any part load change may be found by substituting the new penstock velocity in formula [17], or from the tables direct.

98 From formula [3] we see that d is directly proportional to N (= h.p.) the load. Therefore, if the head is varied the capacity varies as $\sqrt{H^3}$ (h.p. varies as the square root of the head cubed) and for a new head = $\left(H + (DH)\right)$ the capacity of the turbine rises with $\left(H+(DH)\right)^{\frac{3}{2}}$ and the new capacity of the turbine is $N\left(H+(DH)\right)^{\frac{3}{2}}$, which is the case when load is thrown off.

99 When the load is thrown on the available energy decreases with the term

$$\frac{1}{\left(H-(DH)\right)^{\frac{3}{2}}}$$

100 To obtain the results in per cent, these terms are transformed as follows:

For closing gates,

$$\left(1+\frac{(DH)}{H}\right)^{\frac{3}{2}}$$

and, for opening gates,

$$\frac{1}{\left(1-\frac{(DH)}{H}\right)^{\frac{3}{2}}}$$

so that finally we get a speed variation d modified by pressure variations $\pm \frac{(DH)}{H}$ as given by the following formulae:

For closing gates (load thrown off)

$$d''' = d_{\text{eff}} \left(1 + \frac{(DH)}{H}\right)^{\frac{3}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [18]$$

for opening gates (load thrown on)

$$d''' = \frac{d_{\text{eff}}}{\left(1 - \frac{(DH)}{H}\right)^{\frac{3}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [19]$$

101 After making a number of calculations according to these formulae, it will be noted that the results from both are practically identical within certain limits. That they are not identical throughout the range of the pressure variation tables can be seen from the following:

For

$$-\frac{(DH)}{H} = 1\ (100\ \%)$$

$$d''' = \frac{d_{\text{eff}}}{(1-1)^{\frac{3}{2}}} = \text{infinity}$$

whereas for

$$+\frac{(DH)}{H} = 1$$

$$d''' = d_{\text{eff}}\ (1+1)^{\frac{3}{2}} = \text{a definite value}$$

102 This shows us that, up to a point where $\frac{(DH)}{H} = \pm 1$, the results for d''' are practically identical for opening or closing the gates. Then the d''' curve turns up for opening and becomes infinity with $-\frac{(DH)}{H} = 1$, while the d''' curve for closing gates goes on undisturbed as shown by the accompanying diagram, (Fig. 6).

103 This indicates that for practical problems, where $-\frac{(DH)}{H}$ would never be allowed to reach the value of 1, it is not necessary to calculate d''' for both opening and closing gates, but that either one of the formulae [18] and [19] will give the desired results. As $-\frac{(DH)}{H}$ approaches 100%, d''' for opening gates becomes considerably greater

than d''' for closing gates. In such cases, it is well to calculate d''' for both movements, particularly as frequently it is not necessary that d''' for opening gates be as low as d''' for closing gates.

104 From observation of the tables on pressure variations, it will be noted that a change in velocity of 1 ft. will have considerable effect on the pressure variation, and this velocity should always be kept as low as is consistent with a reasonable investment. We should always keep in mind that by decreasing our penstock velocities, we not only help our pressure variations, and hence speed regulation, but use the water more economically, since our friction head will be less as the velocity becomes less.

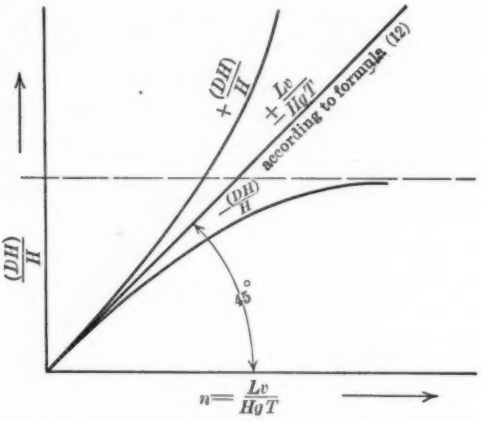


FIG. 7 COMPARISON OF PRESSURE VARIATIONS FOR RIGID AND FLEXIBLE PENSTOCKS

PRESSURE REGULATOR

105 If a reasonable solution cannot be found in the foregoing, such as will satisfy both engineering and commercial conditions, or either, it will become necessary to consider one or more practical appurtenances which are discussed in what follows. Economically, it will often prove desirable to consider these, even if not necessary to a solution of the problem from an engineering point of view.

106 A pressure regulator is a device attached to the turbine casing or penstock near the turbine, and operated from the governor in such a manner that when the turbine gates are closed suddenly and a sufficient amount to disturb the regulation on account of pressure rise, the regulator will be opened by the governor, sufficiently to keep the pres-

sure rise within reasonable limits. Such a pressure regulator should be adjustable so that the amount of pressure rise for any given load change can be predetermined for any set of conditions. It should close automatically and slowly under usual conditions so that its sudden closure will not produce a pressure rise. It should, however, be so arranged, that if a sudden increase should occur after a sudden decrease in load during which the regulator is opened, the governor will close the regulator quickly and positively. Otherwise water then needed to prevent an excessive pressure drop would pass through the regulator while it was slowly closing. Such pressure regulators can be designed practically, with all the functions described, and if of sufficient size the maximum pressure rise will not exceed 10% above normal with a load change of 100%. It will be seen from our subsequent discussion that for a fixed set of conditions, the pressure drop is always less than the pressure rise, which at once shows us the value of the pressure regulator.

107 From tests made by the writer and substantiated by others, the pressure rise in a turbine, and consequently in the penstock feeding a turbine, depends directly upon the discharge capacity of the pressure regulator, if properly designed, and upon the sensitiveness of the operating mechanism of the pressure regulator. The latter should be adjustable, so that the pressure regulator can be set to meet the requirements of any fixed conditions after being installed.

108 If the sensitiveness of the pressure regulator is 10%; that is, if the operating mechanism is so adjusted that it will open if a sudden load change amounting to 10% of the total load occurs, the pressure rise will be as follows:

Discharge capacity, 100% of turbine discharge, pressure rise 10%
Discharge capacity, 75% of turbine discharge, pressure rise 20%
Discharge capacity, 50% of turbine discharge, pressure rise 30%

109 Due to the insensitiveness of the operating mechanism, the pressure rise will be the same regardless of the load, and will be even slightly greater for a small load change than a large one, as it will take proportionally more time to open sufficiently to pass the small quantity of water. Another factor which helps to bring this about is the discharge coefficient of the pressure regulator, as this is greater the larger the opening. In calculating the effect on the speed regulation of the pressure rise, it is therefore necessary to take this into consideration for a partial load change as well as a full load change.

110 As already explained, although $-\frac{(DH)}{H}$ is always less than $+\frac{(DH)}{H}$, the corresponding regulation as affected by these pressure variations is practically the same, at least within the usual limits. If this is the case, it would appear that a pressure regulator is of no value in improving speed regulation. However, in most plants the load is thrown off much more suddenly than it is thrown on, the few exceptions usually occurring in small plants which always require more careful consideration with respect to the subject of speed regulation.

111 A lighting load is usually turned on as suddenly as turned off, but its proportion to the total load is exceedingly small, a few lights usually being turned on at a time. Motor loads are usually turned on very slowly by means of resistances or otherwise, and such sudden loads as may come on the motor during its operation are generally only a small part of the total load. On the other hand, a motor load is usually thrown off suddenly, whether purposely or accidentally, so that it becomes more difficult to maintain constant speed for load thrown off than for load thrown on, and it is of great benefit to have conditions for good regulation better for that case.

112 This benefit is obtained by means of the pressure regulator, as $+\frac{(DH)}{H}$ may be reduced to such an extent that its effect on the speed regulation is very small.

113 It is of course evident that a pressure drop of less than 100% is not dangerous to the penstock, whereas a pressure rise much less than 100% may be very dangerous, particularly if it occurs frequently. In this case it is liable to crystallize the penstock material, especially at the rivetted joints, so that the penstock may give way with a pressure rise much within the limit set by the original factor of safety. In such a case, the pressure regulator not only assists in the regulation of speed but protects the penstock as well.

114 When a pipe line or penstock is laid over a rough country, or where it descends precipitous hillsides after running along a comparatively gentle slope, care must be taken that the water will never be accelerated so quickly at a change in slope that the water column can break and thus exceed or even approach the maximum pressure drop of 100%. In such a case the penstock is in danger either of collapsing or of being shattered by a possible water ram.

115 It is uncommercial to provide against something that may never happen and if the greatest load change ever expected under normal operation is 25%, it would be a waste of money to provide for 100% change of load, as far as speed regulation is concerned.

116 Yet it is always necessary to consider the effect of the maximum pressure rise for 100% load change, since in the case of a short circuit or break in the governor such an extreme load change may occur and subject the penstock to the corresponding pressure rise.

117 It may therefore be desirable to install a pressure regulator simply to protect the penstock with entire disregard of the regulation, which may be commercially satisfactory without it.

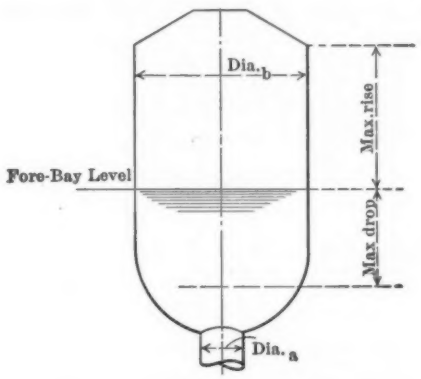


FIG. 8. PRACTICAL DESIGN FOR A HIGH STANDPIPE

EQUALIZING RESERVOIR AND STANDPIPE

118 As has just been stated above, the pressure drop is always less than the pressure rise, and as long as the pressure drop is within such limits as will permit satisfactory regulation, the pressure rise can be kept within safe limits by means of the pressure regulator. When, however, the point is reached where the pressure drop is excessive, the problem is again altered. The practical solution of such a problem is by means of an "equalizing reservoir," or a "standpipe." The effect of either is the same, namely, to reduce the effective length of the penstock, and to supply or take up water during a change of load, while the flow of the same amount of water will be accelerated or retarded in that portion of the penstock beyond the reservoir or standpipe. In small plants the equalizing reservoir is seldom used, as the

same effect can be had cheaper with a standpipe. However, in large plants under medium heads, where the quantity of water used is considerable, the reservoir will usually prove more economical in first cost and of much greater benefit to pressure variations and hence to speed regulation. The larger the surface area of a reservoir or standpipe, the smaller will be the pressure variation, which at once shows the advantage of the reservoir.

119 The topography of the country surrounding a power site usually decides whether a reservoir or standpipe should be used, as entirely artificial reservoirs may prove very expensive, and in such cases the standpipe is resorted to. It will be often found advantageous to change the shortest or most economical route of the pipe line to one more circuitous, in order to use a natural reservoir site, or to bring

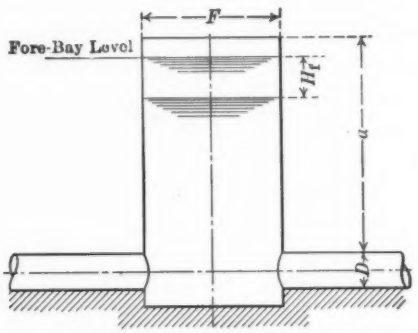


FIG. 9 MINIMUM DIMENSIONS OF A STANDPIPE

either the reservoir or the standpipe closer to the power house. If the standpipe is of suitable diameter and close to the turbine, the speed regulation will approach that obtainable with an open flume. Otherwise the problem becomes that of a plant with a closed penstock, of a length equal to that of the draft tube, plus the length of the penstock from the turbine to the standpipe, plus the height of the standpipe itself. To approach more nearly the effect of regulating reservoirs, high standpipes should have their upper part enlarged, in the shape of a tank (Fig. 8). This tank may be supported on structural steel columns. The pipe leading to this tank should be of a diameter not less than that of the penstock. Where a power house is located near a gently sloping hillside, the standpipe may be laid up this hillside and supported by it, instead of being supported by columns or

otherwise. Standpipes for heads of a thousand feet have thus been built.

120 The standpipe should be located as near the turbine as possible as has been previously stated. If it is arranged with an overflow, the pressure rises can be practically eliminated, and the pressure drop will depend directly upon the size or capacity.

121 The minimum height of such a standpipe is determined by the restriction that in no case must the water level in it drop to such a point as would admit air into the penstock. This condition is satisfied by the following equations (Fig. 9):

$$a > \sqrt{\frac{Q}{F} \times \frac{L \times v}{g}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [20]$$

$$a \geqq D + Hf \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [21]$$

Where

Q = cu. ft. per sec.
F = area of standpipe in sq. ft.
L = pipe line length above standpipe in ft.
v = pipe line velocity in ft. per sec.
Hf = friction head in ft.
D = diameter of penstock in ft.

122 It is seldom satisfactory to have the standpipe overflow and furthermore it is not economical. They are usually built high enough so that the water cannot overflow, even with a maximum load change. In northern climates, where there is danger of freezing, the entire standpipe should be well lagged and quite often it must be provided with steam-pipe coils, supplied with steam from a boiler installed at the foot of the standpipe.

123 In order to reduce the height of the standpipe as much as possible, the slope of the pipe line should be as little as is consistent with the velocity head and friction head required, as the top of the standpipe must in any case be higher than the level of the water in the forebay to meet the conditions of a shutdown with pipe line full.

124 If load is suddenly thrown on, a certain time will elapse before the water accelerates in that part of the pipe between the standpipe and the turbine, another and longer time elapses before the water in the part of the pipe above the standpipe accelerates to the velocity required by the new load. During the latter time, the stand-pipe must supply the turbine with a quantity of water which is the difference between that used by the turbine and that supplied by that part

of the pipe above the standpipe at the reduced velocity during acceleration. The reverse is true when load is thrown off.

125 The actions of the water in a plant with standpipe or equalizing reservoir are easily explained, but very difficult to compute. In the following will be found a practical method for calculating standpipe dimensions. No attempt is made to give the derivation of the formulae, as that in itself would require a paper of some length.

126 Let

L = length of pipe line between standpipe and intake
D = average diameter of pipe line in ft.
F_p = average area of pipe line in sq. ft.
F_s = average area of standpipe in sq. ft.
Q = water discharged by turbines in cu. ft. per sec.
v = average velocity of water in pipe line in ft. per sec.
y = drop of water level in standpipe when Q cu. ft. of water is flowing continuously
y_{max} = maximum drop or rise of water level
h_f = friction loss in ft. in the pipe line $= f \frac{L}{D} \frac{v^2}{2g} = av^2$
$a = \frac{fL}{D2g}$ = a function of the velocity, however assumed to be constant
f = friction coefficient = 0.015 for new plate steel pipe
g = 32.2 ft. per sec. = acceleration of gravity
Dy = change of level of standpipe
Dv = change of velocity in pipe line
Dt = time element in sec.

Then

$$Dy = \left(\frac{Q}{F_s} - \frac{F_p}{F_s} v \right) Dt \quad \text{.....[22]}$$

and

$$Dv = \frac{g}{L} \left(y - av^2 \right) Dt \quad \text{.....[23]}$$

127 From these two formulae y can be computed for any time interval and the results plotted with time in seconds as abscissae and y in feet as ordinates.

128 The resulting curve (Fig. 10) shows the maximum drop or rise of the water level for any assumed or existing pipe line and standpipe combination.

129 If it is desired to approximate the proper capacity of a standpipe or equalizing reservoir in order not to exceed an assumed or desired pressure rise or drop, we must proceed as follows.

130 Referring to par. 54 we find the formula for the accelerating or decelerating time for a column of water as follows:

$$T = \pm \frac{Lv}{Hg \dfrac{(DH)}{H}}$$

$\dfrac{(DH)}{H}$ is the assumed or desired pressure rise or drop.

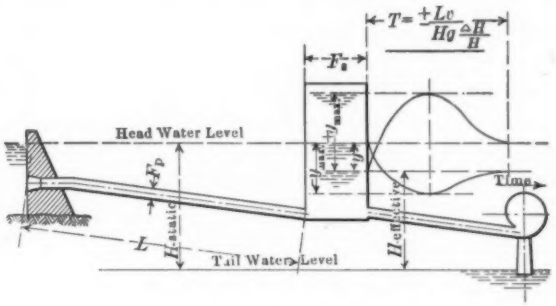


FIG. 10 PRESSURE VARIATIONS WITH STANDPIPE

131 If we now let S represent the governor opening or closing time, then the equalizing capacity $C = Q\ (T - S)$ in cu. ft. and the area

$$F_s = \frac{C}{h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [24]$$

where

$$h = h_f + \frac{(DH)}{H}\left(H \pm h_f\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots [25]$$

132 The theory from which these formulae result was first derived by Engineer Pressel and published by him in the Schweizerische Bauzeitung, January 1909, under the title Dimensionierung von Wasserschloessern.

133 A very thorough, though highly theoretical study of this subject was published in the same journal in 1908 by Prof. Franz Prasil, under the title of Wasserschlossprobleme.

134 Although not so economical in the use of water, it will often prove more economical in first cost of plant, to install a pressure regulator rather than build the standpipe to the height as found necessary by the preceding equations. With a suitable pressure regulator in the system, the height of the standpipe above the forebay water level is more or less a question of judgment, but if made equal to the depth, it will always prove sufficient. It should be remembered, however, that a pressure regulator is only a mechanical device, somewhat complicated, and many engineers would be unwilling to risk a catastrophe, in case of a sudden full load change with the pressure regulator out of order.

135 With the same purpose in view, namely, the reduction of the height of the standpipe, it may sometimes prove expedient to provide water rheostats connected to the low-tension bus-bars, with an oil switch in the connection. By means of a mechanical trip on the governor or gate mechanism the control circuit of the switch can be closed at any desired gate opening or power output, so that in case of a short circuit part of the load will be switched onto the water rheostats. This will reduce the pressure rise and therefore the height of the standpipe necessary and will at the same time keep the voltage of the generators in perfect control. After the load is again picked up, the switches connecting the rheostats can be opened from the switchboard, the rheostats being left in the water at all times. This scheme is of course applicable only under certain load conditions.

136 Equalizing reservoirs are usually provided with an overflow or spill-way, so that their maximum height need not exceed that of the forebay level.

137 From the foregoing it will be seen that the location of the standpipe or regulating reservoir cannot always be as desired, and the solution of the problem of pressure variation is in many cases only partially solved by them. It is true that an entirely artificial reservoir or a standpipe could be located almost at will, but the cost would usually prove excessive, and, unless a natural site for either is available, their distance from the power house will reduce itself largely to a question of cost, and the cost of increased flywheel effect must be balanced against the cost of closer proximity of standpipe to turbine, to produce the desired regulation.

138 As already stated in our discussion of the pressure regulator, the pressure drop is always less than the pressure rise, so that it is necessary only to bring the standpipe near enough to prevent excessive pressure drop, disregarding the pressure rise and providing for it by means of a pressure regulator.

139 The capacity of a standpipe must be the same regardless of the distance it is located from the turbine, provided the other conditions, such as maximum change of load to be provided for and regulalating time are the same. If a greater regulating time is allowed on account of having a longer penstock, the capacity of the standpipe could theoretically be reduced slightly, but this should not be done in practice, and the formulae given therefore hold good for any conditions.

140 In a plant with long penstocks, where it is impossible to install a standpipe, and where it is practically out of the question to increase the size of the penstocks on account of excessive cost or otherwise, it will often be found impracticable to provide sufficient flywheel effect to obtain satisfactory regulation.

SYNCHRONOUS BYPASS

141 If this is the case in connection with reaction turbines, a synchronous bypass must be provided which should be exactly what the name implies; that is, it should discharge that part of the full load flow of the water which is not passing through the turbine at any given time. If the flow of the water through the turbine is changed in volume, the change in flow through the bypass should correspond.

142 It is very difficult to design a bypass that will do this, since the discharge through the turbine gates is not proportional to the governor stroke, from which the bypass must be operated, and furthermore the coefficient of discharge of the bypass cannot be kept constant during its full range of opening. Due to these causes and the insensitiveness of the governor, the pressure variations both ways may be quite considerable with the synchronous bypass and should be considered in computing the speed regulation. They may be as high as 25%, but the writer's experience shows that they can be kept as low as 10% for both opening and closing gates. The bypass should always be brought as near as possible to the turbine gates and in line with the flow of water into them.

DEFLECTING NOZZLE

143 In the case of impulse turbines, the synchronous bypass may also be used, but the deflecting nozzle is more generally used in practice, as it has several important advantages. With the latter the flow of water is not interfered with, but the stream is partially or wholly

deflected from the buckets, maintaining practically constant pressure, and varying the active volume only. The problem therefore reduces itself into one identical with that of a turbine in open flume, or without pressure variations, and the regulation is subject only to the fly-wheel effect.

144 Both of the devices mentioned above, and which are too well known to require detailed description, are extremely wasteful, and although numerous modifications have been made to reduce their wastefulness, such devices usually interfere with automatic regulation and the lessening of their wastefulness is one of degree only. In places where fixed quantities of water must be passed, regardless of the load on the plant, such as in plants where no storage whatever is available, or where irrigation or other laws require it, these two methods of regulation may prove the proper solution.

145 No solution of a problem in speed regulation is commercially correct, unless accompanied by an analysis of the probable load curve of the power plant to be regulated. It is evidently useless to provide against something which will never occur. Thus, if a plant consists of a number of large units, the greatest load change to be considered should be carefully gone into. This decided, it should be known over how many units the load change must be distributed; in other words, what will be the least number of units running in parallel on one circuit. In a large plant it is very seldom necessary to consider a total load change, (100% change of load) whereas in small plants this may frequently occur, especially when only one unit is running

AIR CHAMBER

146 Upon first consideration, it appears that an air chamber would be an ideal means to provide against extreme pressure variations. The necessary volume of such a device can be computed from the following formula:

$$V = \frac{T \times v}{\frac{(D\,H)}{H}} \qquad [26]$$

where

V = volume of air chamber in cu. ft.

T = accelerating time $= \frac{Lv}{gH}$

v = velocity in penstock in ft. per sec.

$\frac{(DH)}{H}$ = permissible pressure variation

147 It will be usually found that extremely large and therefore expensive air chambers are required. However, leaving the cost out of consideration, there is a constant danger connected with this device, since the water absorbs the air, so that it may not only be of no use, but may greatly increase the pressure variations. Although such modifications of the simple air chamber as automatically operated air compressors and check valves at the penstock connection have been suggested, they should be used only as a last resort.

TABLE 1 CHARACTERISTICS OF STANDARD REACTION TURBINE RUNNERS

Specific speed $k = \frac{\text{r.p.m.}}{H}\sqrt{\frac{\text{h.p.}}{\sqrt{H}}}$ = speed in r.p.m. of a turbine runner diminished in all dimensions to such an extent as to develop 1 h.p. when working under the head $H = 1$ ft.

h.p.$_1$ = horsepower per 1-ft. head = $\frac{\text{h.p. for any head}}{H. \times \sqrt{H}}$. Power varies as $\sqrt{H^3}$. Therefore h.p. for any head = h.p.$_1 \times H \times \sqrt{H}$.

r.p.m.$_1$ = revolutions per 1-ft. head = $\frac{\text{r.p.m.}}{\sqrt{H}}$. Speed varies as $\sqrt{H}$. Therefore r.p.m. = r.p.m.$_1 \times \sqrt{H}$.

Q_1 = quantity per 1-ft. head = $\frac{Q}{\sqrt{H}}$. Discharge varies as $\sqrt{H}$. Therefore $Q = Q_1 \times \sqrt{H}$

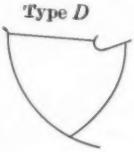
Type *A*				Type *B*			Type *C*			Type *D*		
												
Specific speed $k = 13.55$				$k = 20.3$			$k = 29.4$			$k = 40.7$		
Peripheral speed $u_1 = 0.585$				$u_1 = 0.625$			$u_1 = 0.665$			$u_1 = 0.70$		
Diam.	r.p.m.$_1$	h.p.$_1$	Q_1	r.p.m.$_1$	h.p.$_1$	Q_1	r.p.m.$_1$	h.p.$_1$	Q_1	r.p.m.$_1$	h.p.$_1$	Q_1
15	71.7	0.0358	0.38	76.7	0.0705	0.791	81.5	0.130	1.35	85.6	0.226	2.38
18	59.8	0.0514	0.55	64.0	0.105	1.10	68.0	0.187	1.95	71.5	0.324	3.42
21	51.2	0.0705	0.75	54.7	0.1385	1.45	58.2	0.225	2.34	61.3	0.442	4.64
24	44.75	0.0915	0.975	47.8	0.182	1.91	51.0	0.333	3.46	53.55	0.577	6.08
27	39.8	0.116	1.235	42.5	0.229	2.41	45.2	0.423	4.40	47.6	0.731	7.70
30	35.8	0.1425	1.52	38.25	0.284	2.982	40.2	0.520	5.40	42.8	0.902	9.47
34	31.65	0.184	1.96	33.8	0.363	3.82	36.0	0.668	6.95	37.8	1.158	12.20
38	28.25	0.23	2.442	30.2	0.453	4.78	32.2	0.835	8.68	33.8	1.444	15.20
42	25.65	0.28	2.98	27.4	0.551	5.80	29.1	1.016	10.55	30.6	1.765	18.50
46	23.40	0.336	3.58	25.0	0.665	7.00	26.6	1.225	12.78	27.9	2.120	22.3
50	21.50	0.398	4.24	22.9	0.790	8.40	24.4	1.450	15.10	25.65	2.50	26.3
55	19.56	0.48	5.12	20.9	0.950	10.00	22.25	1.745	18.10	23.30	3.04	32.0
60	17.90	0.573	6.10	19.1	1.130	11.90	20.4	2.08	21.60	21.40	3.61	38.0
65	16.55	0.672	7.15	17.65	1.330	14.00	18.8	2.44	25.40	19.80	4.22	44.2
70	15.40	0.785	8.35	16.40	1.535	16.15	17.5	2.82	29.40	18.35	4.90	51.5

TABLE 1—Continued

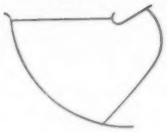
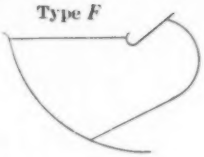
Type *E*				Type *F*			
							
k = 49.7 − 62.8				k = 70.0 − 83.85			
u_1 = 0.72 − 0.78				u_1 = 0.835 − 0.89			
Diam.	r.p.m.$_1$	h.p.$_1$	Q_1	r.p.m.$_1$	h.p.$_1$	Q_1	Diam.
14	94.6	0.277	2.95	110.9	0.410	4.53	14
16	83.6	0.367	3.90	97.0	0.541	5.96	16
18	74.3	0.471	5.02	86.8	0.704	7.77	18
20	67.0	0.597	6.37	77.0	0.912	10.01	20
22	61.0	0.731	7.80	69.7	1.133	12.55	22
24	56.0	0.883	9.42	64.3	1.375	15.20	24
26	52.0	1.055	11.20	59.5	1.623	17.95	26
28	48.1	1.243	13.25	55.3	1.930	21.30	28
30	45.5	1.436	15.30	52.0	2.20	24.30	30
32	42.7	1.65	17.55	49.1	2.555	28.25	32
34	40.3	1.89	20.10	46.6	2.825	31.20	34
36	38.2	2.15	22.80	44.1	3.14	34.75	36
38	36.2	2.42	25.70	41.9	3.52	38.90	38
40	34.5	2.75	29.3	39.8	3.93	43.40	40
42.5	32.5	3.09	33.0	37.5	4.33	47.80	42.5
45	30.8	3.53	37.6	35.8	4.92	54.25	45
47.5	28.8	4.01	42.65	34.0	5.66	62.60	47.5
50	27.8	4.45	47.4	32.3	6.13	67.80	50
52.5	26.6	4.95	52.7	30.8	6.75	74.60	52.5
55	25.45	5.52	58.8	29.9	7.50	82.75	55
57.5	24.3	6.10	65.0	28.2	8.16	90.00	57.5
60	23.4	6.80	72.4	27.05	8.94	98.70	60
64	22.1	7.63	81.25	25.60	10.05	111.0	64
68	20.9	8.57	91.3	24.20	11.34	125.0	68
72	19.8	9.58	102.0	22.58	13.07	144.0	72
76	18.8	10.92	116.0	21.50	14.52	161.0	76
80	17.9	12.30	131.0	20.36	16.29	180.0	80
84	....	....	.....	19.50	17.88	197.0	84
88	....	....	.....	18.60	20.4	225.0	88
92	....	....	.. ..	17.75	22.0	243.0	92
96	....	....	.....	16.85	24.48	270.0	96
100	....	....	.....	16.30	26.46	293.0	100

TABLE 2 PRESSURE VARIATIONS FOR OPENING OR CLOSING TIME OF 1 SEC.

+ Sign Indicates Pressure Rise; — Sign Pressure Drop. To Get Results in Per Cent Multiply Tabular Values by 100.

$\frac{L}{H}$		Velocities in Penstock in Ft. per Sec.														
		1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.	12 ft.	14 ft.	16 ft.	18 ft.	20 ft.
1	+	0.032	0.064	0.098	0.132	0.169	0.205	0.243	0.283	0.322	0.372	0.450	0.545	0.640	0.740	0.850
	−	0.032	0.060	0.090	0.116	0.144	0.172	0.195	0.220	0.244	0.274	0.311	0.351	0.390	0.425	0.460
1.5	+	0.047	0.096	0.150	0.205	0.260	0.322	0.386	0.446	0.520	0.587	0.74	0.90	1.08	1.26	1.46
	−	0.045	0.088	0.131	0.169	0.206	0.244	0.279	0.309	0.342	0.391	0.425	0.475	0.520	0.560	0.595
2	+	0.065	0.132	0.207	0.280	0.360	0.450	0.543	0.638	0.740	0.840	1.07	1.33	1.62	1.91	2.22
	−	0.060	0.116	0.171	0.219	0.265	0.311	0.351	0.388	0.425	0.456	0.515	0.575	0.618	0.655	0.69
2.5	+	0.081	0.168	0.270	0.361	0.470	0.590	0.716	0.850	0.990	1.14	1.46	1.84	2.25	2.69	3.19
	−	0.075	0.143	0.215	0.265	0.320	0.370	0.415	0.460	0.497	0.534	0.593	0.642	0.691	0.727	0.758
3	+	0.098	0.205	0.322	0.450	0.588	0.740	0.905	1.08	1.26	1.47	1.91	2.42	2.99	3.60	4.31
	−	0.090	0.169	0.244	0.310	0.368	0.425	0.471	0.518	0.560	0.598	0.655	0.705	0.748	0.780	0.815
3.5	+	0.116	0.243	0.385	0.544	0.708	0.90	1.11	1.33	1.55	1.86	2.41	3.06	3.81	4.66	5.60
	−	0.104	0.193	0.276	0.550	0.415	0.475	0.528	0.580	0.612	0.655	0.707	0.752	0.791	0.822	0.85
4	+	0.132	0.284	0.453	0.635	0.840	1.07	1.33	1.62	1.91	2.26	2.97	3.82	4.80	5.86	7.10
	−	0.116	0.220	0.312	0.386	0.456	0.522	0.572	0.615	0.655	0.693	0.752	0.791	0.82	0.850	0.89
4.5	+	0.150	0.323	0.520	0.736	0.985	1.26	1.57	1.910	2.28	2.69	3.60	4.66	5.87	7.22	8.72
	−	0.130	0.244	0.343	0.425	0.495	0.556	0.612	0.655	0.692	0.728	0.780	0.822	0.85	0.882	0.90
5	+	0.168	0.364	0.592	0.848	1.130	1.46	1.86	2.24	2.69	3.19	4.26	5.60	7.12	8.75	10.6
	−	0.144	0.266	0.371	0.460	0.531	0.595	0.654	0.693	0.730	0.758	0.810	0.840	0.885	0.910	0.915
6	+	0.206	0.450	0.739	1.08	1.46	1.90	2.44	2.99	3.60	4.31	5.88	7.75	9.90	12.2	14.9
	−	0.171	0.310	0.425	0.515	0.590	0.652	0.712	0.758	0.782	0.812	0.862	0.892	0.917	0.94	0.94
7	+	0.243	0.540	0.902	1.32	1.82	2.40	3.06	3.82	4.66	5.60	7.70	10.2	13.0	15.3	19.9
	−	0.195	0.350	0.478	0.570	0.640	0.712	0.746	0.792	0.822	0.84	0.89	0.92	0.93	0.96	0.96
8	+	0.285	0.640	1.08	1.62	2.24	2.97	3.84	4.81	5.88	7.12	9.80	13.1	16.8	21.0	25.8
	−	0.221	0.390	0.516	0.620	0.695	0.753	0.790	0.83	0.861	0.89	0.925	0.94	0.95	0.975	0.975
9	+	0.322	0.740	1.27	1.92	2.66	3.60	4.72	5.87	7.22	8.75	12.2	16.3	21.1	26.5	32.3
	−	0.244	0.425	0.560	0.660	0.730	0.780	0.82	0.86	0.880	0.92	0.94	0.96	0.97	0.985	0.99
10	+	0.375	0.850	1.47	2.23	3.16	4.27	5.60	7.10	8.75	10.6	14.8	19.9	25.7	32.3	39.6
	−	0.275	0.460	0.595	0.695	0.760	0.81	0.84	0.886	0.895	0.95	0.96	0.98	0.99	1.00	1.00

15	+	0.595	1.460	2.70	4.26	6.28	8.73	11.7	14.8	18.6	22.9	32.2	43.3	57.1	71.5	87.5
	−	0.374	0.595	0.735	0.810	0.86	0.898	0.93	0.945	0.95	0.98	0.98	1.00	1.00	1.00	1.00
20	+	0.850	2.22	4.31	7.02	10.6	14.8	19.9	25.7	32.2	39.8	56.5	76.5	100.0	126.0	155.0
	−	0.461	0.69	0.812	0.87	0.915	0.93	0.94	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00
25	+	1.14	3.20	6.35	10.5	16.0	22.6	30.6	39.5	50.0	61.7	88.0	119.0	156.0	197.0	244.0
	−	0.535	0.765	0.868	0.915	0.96	0.955	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
30	+	1.47	4.30	8.75	14.8	22.6	32.1	44.0	56.5	71.5	88.2	126.0	171.0	225.0	283.0	350.0
	−	0.60	0.81	0.91	0.93	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
40	+	2.25	7.10	15.0	25.5	39.4	56.4	77.2	100.0	127.0	158.0	222.0	3.04	399.0	504.0	621.0
	−	0.695	0.888	0.955	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
50	+	3.21	10.6	22.9	39.7	61.0	87.5	120.0	155.0	198.0	244.0	346.0	475.0	622.0	785.0	970.0
	−	0.772	0.92	0.982	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
60	+	4.31	14.9	32.4	57.00	87.5	105.0	172.0	222.0	282.0	350.0	503.0	688.0	898.0	1130.0	1400.0
	−	0.812	0.955	0.985	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
80	+	7.12	25.8	57.0	100.0	155.0	223.0	306.0	396.0	505.0	620.0	890.0	1215.0	1585.0	2000.0	2480.0
	−	0.90	0.98	0.995	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
100	+	10.60	39.6	88.5	155.0	240.00	347.0	476.0	625.0	785.0	967.0	1395.0	1900.0	2490.0	3140.0	3870.00
	−	0.915	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 3 PRESSURE VARIATIONS FOR OPENING OR CLOSING TIME OF 2 SEC.

+ Sign Indicates Pressure Rise; − Sign Pressure Drop. To Get Results in Per Cent Multiply Tabular Values by 100.

$\frac{L}{H}$		Velocities in Penstock in Ft. per Sec.														
		1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.	12 ft.	14 ft.	16 ft.	18 ft.	20 ft.
1	+	0.016	0.032	0.049	0.064	0.081	0.098	0.116	0.132	0.150	0.169	0.205	0.243	0.283	0.322	0.372
	−	0.016	0.032	0.047	0.060	0.075	0.090	0.104	0.116	0.130	0.144	0.172	0.195	0.220	0.244	0.274
1.5	+	0.024	0.047	0.073	0.096	0.123	0.150	0.165	0.205	0.234	0.260	0.322	0.386	0.446	0.520	0.587
	−	0.024	0.045	0.068	0.088	0.109	0.131	0.142	0.169	0.189	0.206	0.244	0.279	0.309	0.342	0.391
2	+	0.033	0.065	0.098	0.132	0.169	0.207	0.243	0.280	0.322	0.360	0.450	0.543	0.638	0.740	0.840
	−	0.032	0.060	0.090	0.116	0.146	0.171	0.195	0.219	0.244	0.265	0.311	0.351	0.388	0.425	0.456
2.5	+	0.041	0.081	0.123	0.168	0.214	0.270	0.310	0.361	0.416	0.470	0.590	0.716	0.850	0.990	1.140
	−	0.039	0.075	0.109	0.143	0.176	0.215	0.237	0.265	0.294	0.320	0.370	0.415	0.460	0.497	0.534
3	+	0.049	0.098	0.150	0.205	0.262	0.322	0.386	0.450	0.520	0.588	0.740	0.905	1.080	1.260	1.470
	−	0.047	0.090	0.130	0.169	0.209	0.244	0.277	0.310	0.342	0.368	0.425	0.471	0.518	0.560	0.598
3.5	+	0.058	0.116	0.178	0.243	0.311	0.385	0.460	0.544	0.625	0.708	0.90	1.110	1.330	1.550	1.860
	−	0.054	0.104	0.151	0.195	0.239	0.276	0.315	0.350	0.385	0.415	0.475	0.528	0.580	0.612	0.655
4	+	0.066	0.132	0.205	0.284	0.364	0.453	0.549	0.635	0.740	0.840	1.070	1.330	1.620	1.910	2.260
	−	0.062	0.116	0.171	0.222	0.266	0.312	0.350	0.386	0.426	0.456	0.522	0.572	0.615	0.655	0.693
4.5	+	0.073	0.150	0.233	0.323	0.416	0.520	0.625	0.736	0.860	0.985	1.260	1.570	1.910	2.280	2.690
	−	0.068	0.130	0.189	0.244	0.294	0.543	0.385	0.425	0.463	0.495	0.556	0.612	0.655	0.692	0.728
5	+	0.081	0.168	0.261	0.364	0.471	0.592	0.716	0.849	0.988	1.130	1.460	1.860	2.240	2.690	3.190
	−	0.075	0.144	0.209	0.266	0.320	0.371	0.415	0.460	0.496	0.531	0.595	0.654	0.693	0.730	0.758
6	+	0.098	0.206	0.322	0.450	0.590	0.739	0.90	1.080	1.260	1.460	1.90	2.44	2.990	3.60	4.310
	−	0.090	0.171	0.244	0.310	0.360	0.425	0.475	0.515	0.558	0.590	0.625	0.712	0.758	0.782	0.812
7	+	0.116	0.243	0.385	0.540	0.715	0.902	1.110	1.320	1.58	1.82	2.40	3.06	3.82	4.660	5.60
	−	0.104	0.195	0.277	0.350	0.420	0.478	0.525	0.570	0.612	0.640	0.712	0.746	0.792	0.822	0.840
8	+	0.134	0.285	0.450	0.640	0.848	1.080	1.33	1.620	1.910	2.24	2.97	3.84	4.81	5.88	7.12
	−	0.118	0.221	0.312	0.390	0.460	0.516	0.570	0.620	0.655	0.695	0.753	0.790	0.830	0.861	0.890
9	+	0.150	0.322	0.52	0.74	0.99	1.27	1.57	1.92	2.28	2.66	3.60	4.72	5.87	7.22	8.75
	−	0.130	0.244	0.342	0.425	0.496	0.560	0.612	0.660	0.693	0.730	0.780	0.820	0.860	0.880	0.920
10	+	0.169	0.375	0.594	0.850	1.140	1.470	1.840	2.230	2.69	3.160	4.27	5.60	7.10	8.75	10.60
	−	0.144	0.275	0.372	0.460	0.533	0.595	0.650	0.695	0.730	0.760	0.810	0.840	0.886	0.895	0.950

15	+	0.264	0.595	0.99	1.46	2.02	2.70	3.130	4.260	5.25	6.280	8.73	11.70	14.80	18.60	22.90
	−	0.210	0.374	0.497	0.595	0.665	0.735	0.755	0.810	0.840	0.860	0.898	0.930	0.945	0.950	0.980
20	+	0.361	0.850	1.46	2.22	3.16	4.31	5.60	7.020	8.750	10.60	14.80	19.90	25.70	32.20	39.80
	−	0.265	0.461	0.60	0.69	0.76	0.812	0.84	0.87	0.895	0.915	0.930	0.940	0.970	0.980	1.00
25	+	0.473	1.140	2.04	3.20	4.58	6.35	8.30	10.50	13.20	16.00	22.60	30.60	39.50	50.00	61.70
	−	0.322	0.535	0.672	0.765	0.816	0.868	0.898	0.915	0.928	0.960	0.960	0.970	0.990	1.00	1.00
30	+	0.59	1.47	2.69	4.30	6.30	8.75	11.70	14.80	18.60	22.6	32.10	44.0	56.60	71.50	88.2
	−	0.371	0.60	0.73	0.81	0.853	0.910	0.950	0.955	0.960	0.99	0.99	1.00	1.00	1.00	1.00
40	+	0.852	2.20	4.32	7.10	10.70	15.00	19.90	25.50	32.2	39.40	56.40	77.2	100.0	127.0	158.0
	−	0.456	0.695	0.813	0.88	0.92	0.955	0.970	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00
50	+	1.14	3.21	6.32	10.6	16.00	22.90	30.80	39.7	50.0	61.00	87.5	120.0	155.0	198.0	244.0
	−	0.535	0.772	0.877	0.92	0.952	0.982	0.990	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
60	+	1.46	4.31	8.50	14.9	22.60	32.40	43.50	57.00	71.5	87.5	125.0	172.0	222.0	282.0	350.0
	−	0.590	0.812	0.920	0.953	0.980	0.985	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
80	+	2.260	7.120	14.90	25.8	39.60	57.00	77.2	100.0	126.0	155.0	223.0	306.0	396.0	505.0	620.0
	−	0.695	0.90	0.95	0.98	0.995	0.995	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
100	+	3.19	10.60	22.90	39.6	61.80	88.5	120.0	155.0	197.0	240.0	347.0	476.0	625.0	785.0	967.0
	−	0.758	0.915	0.985	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 4 PRESSURE VARIATIONS FOR OPENING OR CLOSING TIME OF 3 SEC.

+ Sign Indicates Pressure Rise; — Sign Pressure Drop. To Get Results in Per Cent Multiply Tabular Values by 100.

$\frac{L}{H}$		Velocities in Penstock in Ft. per Sec.														
		1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.	12 ft.	14 ft.	16 ft.	18 ft.	20 ft.
1	+	0.010	0.022	0.032	0.043	0.053	0.064	0.077	0.087	0.098	0.109	0.132	0.158	0.182	0.205	0.231
	−	0.010	0.020	0.032	0.041	0.051	0.060	0.071	0.081	0.090	0.099	0.116	0.136	0.154	0.172	0.187
1.5	+	0.016	0.032	0.047	0.064	0.081	0.096	0.116	0.132	0.150	0.168	0.205	0.243	0.282	0.322	0.363
	−	0.015	0.031	0.045	0.060	0.075	0.088	0.104	0.116	0.131	0.143	0.169	0.195	0.220	0.244	0.266
2	+	0.022	0.043	0.065	0.087	0.109	0.132	0.158	0.182	0.207	0.231	0.280	0.337	0.392	0.450	0.515
	−	0.020	0.041	0.060	0.081	0.098	0.116	0.136	0.154	0.171	0.187	0.219	0.252	0.282	0.311	0.337
2.5	+	0.026	0.053	0.081	0.109	0.138	0.168	0.198	0.231	0.270	0.296	0.361	0.435	0.515	0.590	0.670
	−	0.025	0.051	0.075	0.099	0.122	0.143	0.166	0.187	0.215	0.229	0.265	0.304	0.337	0.370	0.400
3	+	0.032	0.064	0.098	0.132	0.168	0.205	0.243	0.282	0.322	0.363	0.450	0.540	0.639	0.740	0.844
	−	0.031	0.060	0.090	0.116	0.144	0.169	0.195	0.220	0.244	0.266	0.310	0.350	0.389	0.425	0.459
3.5	+	0.037	0.077	0.116	0.158	0.198	0.243	0.287	0.337	0.385	0.435	0.544	0.657	0.775	0.900	1.040
	−	0.036	0.071	0.104	0.136	0.166	0.193	0.224	0.252	0.276	0.304	0.350	0.395	0.438	0.475	0.520
4	+	0.043	0.087	0.132	0.182	0.231	0.284	0.337	0.392	0.453	0.515	0.635	0.780	0.922	1.070	1.240
	−	0.041	0.081	0.118	0.154	0.187	0.220	0.252	0.282	0.312	0.337	0.386	0.439	0.482	0.522	0.560
4.5	+	0.047	0.098	0.150	0.206	0.270	0.323	0.336	0.454	0.520	0.595	0.736	0.902	1.080	1.260	1.470
	−	0.045	0.090	0.130	0.171	0.215	0.244	0.279	0.311	0.343	0.374	0.425	0.478	0.515	0.556	0.600
5	+	0.053	0.109	0.168	0.231	0.296	0.364	0.435	0.515	0.592	0.670	0.848	1.040	1.240	1.460	1.700
	−	0.051	0.098	0.144	0.187	0.229	0.266	0.304	0.337	0.371	0.400	0.460	0.510	0.560	0.595	0.617
6	+	0.064	0.132	0.206	0.282	0.375	0.450	0.540	0.639	0.739	0.844	1.080	1.330	1.620	1.900	2.220
	−	0.060	0.116	0.171	0.220	0.275	0.310	0.350	0.389	0.425	0.459	0.515	0.572	0.620	0.652	0.690
7	+	0.077	0.159	0.243	0.337	0.435	0.540	0.657	0.775	0.902	1.040	1.320	1.670	2.02	2.40	2.86
	−	0.071	0.138	0.195	0.252	0.304	0.350	0.395	0.438	0.478	0.509	0.570	0.628	0.665	0.712	0.743
8	+	0.087	0.181	0.285	0.392	0.511	0.640	0.775	0.922	1.080	1.240	1.620	2.020	2.50	2.97	3.54
	−	0.081	0.152	0.221	0.282	0.336	0.390	0.438	0.482	0.516	0.560	0.620	0.665	0.718	0.753	0.780
9	+	0.098	0.205	0.322	0.454	0.595	0.740	0.905	1.080	1.270	1.470	1.920	2.40	2.97	3.60	4.29
	−	0.090	0.169	0.244	0.311	0.374	0.425	0.471	0.515	0.560	0.600	0.660	0.712	0.753	0.780	0.810
10	+	0.109	0.231	0.375	0.515	0.670	0.850	1.040	1.240	1.470	1.700	2.230	2.860	3.54	4.27	5.15
	−	0.099	0.187	0.275	0.337	0.400	0.460	0.510	0.560	0.595	0.617	0.695	0.735	0.780	0.810	0.942

15	+	0.168	0.363	0.595	0.844	1.140	1.460	1.860	2.200	2.700	3.210	4.260	5.60	7.10	8.73	10.60
	−	0.143	0.266	0.374	0.459	0.525	0.595	0.654	0.690	0.735	0.772	0.810	0.840	0.887	0.898	0.915
20	+	0.231	0.511	0.850	1.240	1.700	2.22	2.86	3.540	4.310	5.150	7.02	9.40	12.00	14.80	18.20
	−	0.187	0.336	0.461	0.560	0.617	0.690	0.735	0.780	0.812	0.842	0.870	0.890	0.947	0.950	0.980
25	+	0.296	0.670	0.140	1.710	2.380	3.200	4.120	5.150	6.350	7.650	10.50	14.20	18.20	22.60	28.00
	−	0.229	0.400	0.535	0.629	0.700	0.765	0.800	0.842	0.868	0.885	0.915	0.940	0.98	0.99	1.00
30	+	0.363	0.843	1.470	2.220	3.210	4.300	5.60	7.100	8.750	10.60	14.80	19.90	25.50	32.10	39.60
	−	0.266	0.462	0.600	0.690	0.772	0.81	0.840	0.887	0.910	0.915	0.930	0.98	1.00	1.00	1.00
40	+	0.515	1.240	2.250	3.540	5.120	7.100	9.40	12.00	15.00	18.20	25.50	35.30	45.00	56.40	70.00
	−	0.337	0.552	0.695	0.78	0.840	0.888	0.890	0.947	0.955	0.980	0.980	1.00	1.00	1.00	1.00
50	+	0.67	1.70	3.21	5.15	7.65	10.60	14.20	18.20	22.90	28.00	39.70	54.00	70.00	87.50	109.0
	−	0.40	0.617	0.772	0.842	0.885	0.92	0.94	0.98	0.982	0.990	1.00	1.00	1.00	1.00	1.00
60	+	0.844	2.22	4.31	7.10	10.60	14.90	19.90	25.50	32.40	39.60	57.00	77.20	100.0	25.0	54.0
	−	0.459	0.689	0.812	0.887	0.915	0.955	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
80	+	1.240	3.53	7.12	12.00	18.20	25.80	35.30	45.0	57.0	70.0	100.0	137.0	178.0	223.0	276.0
	−	0.56	0.78	0.90	0.947	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
100	+	1.70	5.120	10.60	18.20	28.00	39.6	54.00	70.00	88.50	109.0	155.0	212.0	282.0	347.0	430.0
	−	0.617	0.84	0.915	0.98	0.990	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 5 PRESSURE VARIATIONS FOR OPENING OR CLOSING TIME OF 4 SEC.

+ Sign Indicates Pressure Rise; — Sign Pressure Drop. To Get Results in Per Cent Multiply Tabular Values by 100.

$\frac{L}{H}$		Velocities in Penstock in Ft. per Sec.														
		1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.	12 ft.	14 ft.	16 ft.	18 ft.	20 ft.
1	+	0.008	0.016	0.024	0.032	0.041	0.049	0.058	0.054	0.073	0.081	0.098	0.116	0.132	0.150	0.169
	−	0.008	0.016	0.023	0.032	0.039	0.047	0.054	0.060	0.068	0.075	0.090	0.104	0.116	0.130	0.144
1.5	+	0.012	0.024	0.036	0.047	0.060	0.073	0.087	0.096	0.109	0.123	0.150	0.165	0.205	0.234	0.260
	−	0.012	0.024	0.035	0.045	0.056	0.068	0.081	0.088	0.099	0.109	0.131	0.142	0.169	0.189	0.206
2	+	0.016	0.033	0.047	0.065	0.081	0.098	0.016	0.132	0.150	0.169	0.207	0.243	0.280	0.322	0.360
	−	0.015	0.032	0.045	0.060	0.075	0.090	0.104	0.116	0.130	0.146	0.171	0.195	0.219	0.244	0.265
2.5	+	0.020	0.041	0.060	0.081	0.102	0.123	0.145	0.168	0.189	0.214	0.270	0.310	0.361	0.416	0.470
	−	0.019	0.039	0.056	0.075	0.093	0.109	0.126	0.143	0.159	0.176	0.215	0.237	0.265	0.294	0.320
3	+	0.024	0.049	0.073	0.098	0.123	0.150	0.178	0.205	0.233	0.262	0.322	0.386	0.450	0.520	0.588
	−	0.023	0.047	0.068	0.090	0.109	0.130	0.151	0.169	0.189	0.209	0.244	0.277	0.310	0.342	0.368
3.5	+	0.028	0.058	0.087	0.116	0.145	0.178	0.211	0.243	0.279	0.311	0.285	0.460	0.544	0.625	0.708
	−	0.027	0.054	0.081	0.104	0.126	0.151	0.175	0.193	0.216	0.239	0.276	0.315	0.350	0.385	0.415
4	+	0.032	0.066	0.098	0.132	0.169	0.205	0.243	0.284	0.322	0.364	0.453	0.544	0.625	0.740	0.840
	−	0.031	0.062	0.090	0.116	0.146	0.171	0.195	0.220	0.244	0.266	0.312	0.350	0.386	0.426	0.456
4.5	+	0.036	0.073	0.109	0.150	0.189	0.233	0.279	0.323	0.367	0.416	0.520	0.625	0.736	0.860	0.985
	−	0.035	0.068	0.099	0.130	0.159	0.189	0.216	0.244	0.266	0.294	0.343	0.385	0.425	0.463	0.495
5	+	0.041	0.081	0.123	0.168	0.214	0.261	0.310	0.364	0.414	0.471	0.592	0.716	0.848	0.988	1.130
	−	0.030	0.075	0.109	0.144	0.176	0.209	0.236	0.266	0.289	0.320	3.71	0.415	0.460	0.496	0.531
6	+	0.047	0.098	0.150	0.206	0.262	0.322	0.385	0.450	0.520	0.590	0.739	0.900	1.080	1.260	1.460
	−	0.045	0.090	0.130	0.171	0.209	0.244	0.277	0.310	0.342	0.360	0.425	0.475	0.515	0.558	0.590
7	+	0.058	0.116	0.178	0.243	0.310	0.385	0.460	0.540	0.625	0.715	0.902	1.110	1.320	1.580	1.820
	−	0.054	0.104	0.151	0.195	0.236	0.277	0.315	0.350	0.385	0.420	0.478	0.525	0.570	0.612	0.640
8	+	0.064	0.134	0.206	0.285	0.264	0.450	0.540	0.640	0.740	0.848	1.080	1.330	1.620	1.910	2.240
	−	0.060	0.118	0.171	0.221	0.266	0.312	0.350	0.390	0.426	0.460	0.516	0.570	0.620	0.655	0.695
9	+	0.073	0.150	0.233	0.322	0.414	0.520	0.625	0.740	0.860	0.990	1.270	1.570	1.920	2.28	2.66
	−	0.068	0.130	0.189	0.244	0.289	0.342	0.385	0.425	0.463	0.496	0.560	0.612	0.660	0.693	0.730
10	+	0.081	0.169	0.262	0.375	0.471	0.594	0.715	0.850	0.990	1.140	1.470	1.840	2.23	2.69	3.160
	−	0.075	0.144	0.209	0.275	0.320	0.372	0.420	0.460	0.497	0.530	0.595	0.650	0.695	0.730	0.760

15	+	0.125	0.264	0.414	0.595	0.780	0.990	1.220	1.46	1.70	2.02	2.70	3.130	4.260	5.25	6.28
	−	0.109	0.210	0.289	0.374	0.439	0.497	0.547	0.595	0.617	0.665	0.735	0.755	0.810	0.840	0.86
	+	0.163	0.361	0.590	0.850	1.140	1.460	1.84	2.22	2.690	3.16	4.31	5.60	7.02	8.75	10.60
20	−	0.146	0.265	0.360	0.461	0.533	0.600	0.650	0.690	0.730	0.760	0.812	0.84	0.87	0.895	0.915
	+	0.214	0.473	0.780	1.140	1.550	2.040	2.560	3.20	3.82	4.58	6.35	8.30	10.50	13.20	16.00
25	−	0.176	0.322	0.439	0.535	0.670	0.672	0.713	0.765	0.791	0.816	0.868	0.898	0.915	0.928	0.96
	+	0.262	0.590	0.990	1.470	2.04	2.69	3.450	4.30	5.25	6.300	8.75	11.70	14.80	18.60	22.60
30	−	0.209	0.371	0.497	0.60	0.672	0.730	0.777	0.810	0.840	0.853	0.910	0.950	0.955	0.960	0.99
	+	0.361	0.852	1.460	2.25	3.190	4.32	3.60	7.10	8.50	10.70	15.00	19.90	25.50	32.20	39.40
40	−	0.266	0.456	0.60	0.695	0.758	0.813	0.84	0.888	0.920	0.920	0.955	0.970	0.98	0.990	1.00
	+	0.471	1.140	2.040	3.210	4.58	6.32	8.30	10.60	13.20	16.00	22.80	30.80	39.70	50.00	61.00
50	−	0.320	0.535	0.672	0.772	0.815	0.877	0.898	0.920	0.928	0.95	0.982	1.99	1.00	1.00	1.00
	+	0.590	1.460	2.690	4.31	6.32	8.50	11.70	14.90	18.60	22.60	32.40	43.50	57.00	71.50	87.50
60	−	0.360	0.590	0.730	0.812	0.877	0.920	0.950	0.960	0.945	0.980	0.985	1.00	1.00	1.00	1.00
	+	0.848	2.260	4.320	7.120	0.60	19.90	19.90	25.8	32.20	39.60	57.0	77.20	100.0	126.0	155.0
80	−	0.460	0.695	0.813	0.90	0.915	0.955	0.970	0.98	0.99	0.995	0.995	1.00	1.00	1.00	1.00
	+	1.140	3.190	6.320	10.60	16.10	22.90	30.80	39.60	50.00	81.80	88.5	120.0	155.0	197.0	240.0
100	−	0.533	0.758	0.877	0.915	0.950	0.985	0.990	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 6 PRESSURE VARIATIONS FOR OPENING OR CLOSING TIME OF 5 SEC.

+ Sign Indicates Pressure Rise; − Sign Pressure Drop. To Get Results in Per Cent Multiply Tabular Values by 100.

$\frac{L}{H}$		Velocities in Penstock in Ft. per Sec.														
		1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.	12 ft.	14 ft.	16 ft.	18 ft.	20 ft.
1	+	0.006	0.013	0.019	0.024	0.032	0.038	0.045	0.051	0.058	0.064	0.078	0.091	0.104	0.118	0.132
	−	0.006	0.013	0.019	0.024	0.032	0.037	0.043	0.049	0.054	0.060	0.072	0.083	0.095	0.106	0.116
1.5	+	0.009	0.019	0.028	0.038	0.047	0.058	0.068	0.078	0.087	0.096	0.118	0.139	0.161	0.183	0.205
	−	0.009	0.019	0.028	0.037	0.045	0.054	0.064	0.072	0.081	0.088	0.106	0.112	0.138	0.154	0.169
2	+	0.013	0.024	0.038	0.051	0.065	0.078	0.091	0.104	0.118	0.132	0.161	0.189	0.221	0.250	0.280
	−	0.013	0.024	0.037	0.049	0.060	0.072	0.083	0.095	0.106	0.116	0.138	0.159	0.181	0.200	0.219
2.5	+	0.016	0.032	0.047	0.064	0.081	0.095	0.116	0.132	0.150	0.168	0.205	0.243	0.285	0.322	0.361
	−	0.016	0.032	0.045	0.060	0.075	0.090	0.104	0.116	0.130	0.143	0.169	0.195	0.221	0.244	0.265
3	+	0.019	0.038	0.058	0.078	0.098	0.118	0.139	0.161	0.183	0.205	0.250	0.299	0.346	0.399	0.450
	−	0.019	0.037	0.054	0.072	0.090	0.106	0.112	0.138	0.154	0.169	0.200	0.231	0.256	0.284	0.310
3.5	+	0.022	0.045	0.068	0.091	0.116	0.139	0.165	0.189	0.214	0.243	0.299	0.266	0.414	0.475	0.544
	−	0.022	0.043	0.064	0.083	0.104	0.112	0.141	0.159	0.176	0.193	0.231	0.262	0.289	0.323	0.350
4	+	0.024	0.051	0.078	0.104	0.132	0.161	0.189	0.221	0.250	0.284	0.346	0.414	0.485	0.561	0.635
	−	0.024	0.049	0.072	0.092	0.116	0.138	0.159	0.181	0.200	0.220	0.256	0.289	0.326	0.359	0.386
4.5	+	0.028	0.058	0.087	0.118	0.150	0.183	0.214	0.250	0.285	0.323	0.399	0.475	0.561	0.650	0.736
	−	0.028	0.054	0.081	0.106	0.130	0.154	0.175	0.200	0.222	0.244	0.284	0.327	0.259	0.396	0.425
5	+	0.032	0.64	0.098	0.132	0.168	0.205	0.243	0.285	0.322	0.364	0.446	0.540	0.640	0.740	0.848
	−	0.032	0.060	0.090	0.116	0.144	0.169	0.195	0.221	0.244	0.266	0.309	0.350	0.390	0.425	0.460
6	+	0.038	0.078	0.118	0.161	0.206	0.250	0.299	0.346	0.399	0.450	0.561	0.678	0.800	0.932	1.080
	−	0.037	0.072	0.106	0.138	0.171	0.200	0.231	0.256	0.284	0.310	0.359	0.405	0.445	0.483	0.515
7	+	0.045	0.091	0.139	0.189	0.243	0.299	0.366	0.414	0.475	0.540	0.678	0.822	0.988	1.150	1.320
	−	0.043	0.083	0.112	0.159	0.195	0.231	0.262	0.289	0.321	0.350	0.405	0.451	0.496	0.537	0.570
8	+	0.051	0.104	0.161	0.221	0.285	0.346	0.414	0.485	0.561	0.640	0.800	0.988	1.180	1.390	1.620
	−	0.049	0.095	0.138	0.181	0.221	0.256	0.289	0.326	0.359	0.390	0.445	0.496	0.542	0.580	0.620
9	+	0.058	0.118	0.183	0.250	0.322	0.399	0.475	0.561	0.650	0.740	0.932	1.150	1.390	1.630	1.920
	−	0.054	0.106	0.154	0.200	0.244	0.284	0.321	0.359	0.396	0.425	0.483	0.537	0.580	0.615	0.660
10	+	0.064	0.132	0.206	0.283	0.375	0.446	0.540	0.640	0.740	0.850	1.080	1.330	1.620	1.920	2.230
	−	0.060	0.116	0.171	0.220	0.275	0.309	0.350	0.390	0.425	0.460	0.516	0.572	0.618	0.660	0.695

15	+	0.098	0.206	0.322	0.446	0.595	0.740	0.902	1.080	1.270	1.460	1.920	2.410	2.990	3.530	4.260
	−	0.090	0.171	0.244	0.309	0.374	0.425	0.478	0.520	0.560	0.595	0.660	0.707	0.748	0.780	0.810
20	+	0.132	0.285	0.450	0.638	0.850	1.080	1.320	1.620	1.920	2.220	2.990	3.82	4.800	5.87	7.020
	−	0.116	0.221	0.310	0.388	0.461	0.516	0.570	0.618	0.660	0.690	0.748	0.791	0.820	0.860	0.870
25	+	0.168	0.375	0.595	0.850	1.140	1.470	1.820	2.250	2.660	3.200	4.310	5.600	7.120	8.750	10.50
	−	0.143	0.275	0.374	0.460	0.535	0.600	0.640	0.691	0.730	0.765	0.812	0.840	0.885	0.898	0.915
30	+	0.206	0.450	0.740	1.080	1.470	1.920	2.410	2.990	3.530	4.30	5.870	7.750	9.900	12.20	14.80
	−	0.171	0.310	0.425	0.518	0.600	0.660	0.707	0.748	0.780	0.810	0.860	0.892	0.917	0.940	0.950
40	+	0.285	0.640	1.080	1.620	2.250	2.990	3.820	4.800	5.870	7.100	9.900	13.10	16.80	21.00	25.50
	−	0.221	0.390	0.518	0.615	0.695	0.758	0.791	0.820	0.860	0.888	0.917	0.940	0.950	0.970	0.98
50	+	0.375	0.850	1.470	2.240	3.210	4.310	5.600	7.120	8.750	10.60	14.90	19.90	25.70	32.40	39.70
	−	0.275	0.461	0.600	0.693	0.772	0.812	0.840	0.885	0.898	0.920	0.950	0.98	0.965	0.980	1.00
60	+	0.540	1.320	1.920	2.990	4.310	5.870	7.750	9.900	12.20	14.90	21.00	28.40	36.60	46.20	57.00
	−	0.350	0.570	0.660	0.758	0.812	0.860	0.892	0.917	0.940	0.955	0.970	0.995	1.00	1.00	1.00
80	+	0.640	1.620	2.990	4.810	7.120	9.80	13.10	16.80	21.00	25.80	30.60	49.00	64.50	81.00	100.0
	−	0.390	0.620	0.758	0.83	0.900	0.925	0.940	0.940	0.970	0.98	0.985	1.00	1.00	1.00	1.00
100	+	0.850	2.25	4.310	7.100	10.60	14.90	19.90	25.70	32.4	39.50	56.70	76.5	100.0	128.0	155.0
	−	0.461	0.695	0.812	0.885	0.915	0.955	0.98	0.965	0.980	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 7 PRESSURE VARIATIONS FOR OPENING AND CLOSING TIME OF 6 SEC.

+ Sign Indicates Pressure Rise; − Sign Pressure Drop. To Get Results in Per Cent Multiply Tabular Values by 100.

$\frac{L}{H}$		Velocities in Penstock in Ft. per Sec.														
		1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.	12 ft.	14 ft.	16 ft.	18 ft.	20 ft.
1	+	0.005	0.010	0.016	0.022	0.026	0.032	0.037	0.043	0.049	0.053	0.064	0.077	0.087	0.098	0.109
	−	0.005	0.010	0.016	0.020	0.025	0.032	0.036	0.041	0.047	0.051	0.060	0.071	0.081	0.090	0.99
1.5	+	0.008	0.016	0.024	0.032	0.041	0.047	0.058	0.064	0.073	0.081	0.096	0.116	0.132	0.150	0.168
	−	0.008	0.015	0.024	0.031	0.039	0.045	0.054	0.060	0.068	0.075	0.088	0.104	0.116	0.131	0.143
2	+	0.010	0.022	0.033	0.043	0.053	0.065	0.077	0.087	0.098	0.109	0.132	0.158	0.182	0.207	0.231
	−	0.010	0.020	0.032	0.041	0.051	0.060	0.071	0.081	0.090	0.098	0.116	0.136	0.154	0.171	0.187
2.5	+	0.013	0.026	0.041	0.053	0.068	0.081	0.098	0.109	0.123	0.138	0.168	0.198	0.231	0.270	0.296
	−	0.013	0.025	0.039	0.051	0.064	0.075	0.090	0.099	0.109	0.122	0.143	0.166	0.187	0.215	0.229
3	+	0.016	0.032	0.049	0.064	0.081	0.098	0.116	0.132	0.150	0.168	0.205	0.243	0.282	0.322	0.363
	−	0.016	0.031	0.047	0.060	0.075	0.090	0.104	0.116	0.130	0.144	0.169	0.195	0.220	0.244	0.266
3.5	+	0.018	0.037	0.058	0.077	0.098	0.116	0.139	0.158	0.178	0.198	0.243	0.287	0.337	0.385	0.435
	−	0.018	0.036	0.054	0.071	0.090	0.104	0.122	0.136	0.151	0.166	0.193	0.224	0.252	0.276	0.304
4	+	0.022	0.043	0.066	0.087	0.109	0.132	0.158	0.182	0.205	0.231	0.284	0.337	0.392	0.453	0.515
	−	0.020	0.041	0.062	0.081	0.099	0.116	0.136	0.154	0.171	0.187	0.220	0.252	0.282	0.312	0.337
4.5	+	0.024	0.047	0.073	0.098	0.123	0.150	0.181	0.206	0.233	0.270	0.323	0.385	0.454	0.520	0.595
	−	0.023	0.045	0.068	0.090	0.109	0.130	0.152	0.171	0.189	0.215	0.244	0.279	0.311	0.343	0.374
5	+	0.026	0.053	0.081	0.109	0.138	0.168	0.198	0.231	0.261	0.296	0.364	0.435	0.515	0.592	0.670
	−	0.025	0.051	0.075	0.098	0.122	0.144	0.166	0.187	0.209	0.229	0.266	0.304	0.337	0.371	0.400
6	+	0.032	0.064	0.098	0.132	0.168	0.206	0.243	0.282	0.322	0.375	0.450	0.540	0.639	0.739	0.844
	−	0.031	0.060	0.090	0.116	0.143	0.171	0.195	0.220	0.244	0.275	0.310	0.350	0.389	0.425	0.459
7	+	0.037	0.077	0.116	0.159	0.198	0.243	0.287	0.337	0.385	0.435	0.540	0.657	0.775	0.902	1.040
	−	0.036	0.071	0.104	0.138	0.166	0.195	0.224	0.252	0.277	0.304	0.350	0.395	0.438	0.478	0.509
8	+	0.043	0.087	0.134	0.181	0.231	0.285	0.337	0.392	0.450	0.511	0.640	0.775	0.922	1.080	1.240
	−	0.041	0.081	0.118	0.152	0.187	0.221	0.252	0.282	0.312	0.336	0.390	0.438	0.482	0.516	0.560
9	+	0.047	0.098	0.150	0.205	0.270	0.322	0.385	0.454	0.520	0.595	0.740	0.905	1.080	1.270	1.470
	−	0.045	0.090	0.130	0.169	0.215	0.244	0.279	0.311	0.342	0.374	0.425	0.471	0.515	0.560	0.600
10	+	0.053	0.109	0.169	0.231	0.296	0.375	0.435	0.515	0.594	0.670	0.850	0.104	1.240	1.470	1.700
	−	0.051	0.099	0.144	0.187	0.229	0.275	0.304	0.337	0.372	0.400	0.460	0.510	0.560	0.595	0.617

15	+	0.081	0.168	0.264	0.363	0.473	0.595	0.716	0.844	0.990	1.140	1.460	1.860	2.220	2.700	3.210
	−	0.075	0.143	0.210	0.266	0.322	0.374	0.415	0.459	0.497	0.525	0.595	0.654	0.690	0.735	0.772
20	+	0.109	0.231	0.361	0.511	0.672	0.850	1.040	1.240	1.460	1.700	2.220	2.86	3.540	4.310	5.150
	−	0.099	0.187	0.265	0.336	0.400	0.461	0.510	0.560	0.600	0.617	0.690	0.735	0.780	0.812	0.842
25	+	0.138	0.296	0.473	0.670	0.902	1.140	1.470	1.710	2.040	2.320	3.200	4.120	5.150	6.350	7.650
	−	0.122	0.229	0.322	0.400	0.478	0.535	0.600	0.629	0.672	0.700	0.765	0.80	0.842	0.868	0.885
30	+	0.168	0.363	0.590	0.843	1.140	1.470	1.860	2.220	2.690	3.210	4.300	5.600	7.100	8.78	10.60
	−	0.143	0.266	0.371	0.462	0.525	0.600	0.654	0.690	0.730	0.771	0.810	0.84	0.887	0.910	0.915
40	+	0.231	0.515	0.852	1.240	1.700	2.250	2.860	3.540	4.320	5.120	7.100	9.40	12.00	15.00	18.20
	−	0.187	0.337	0.456	0.552	0.617	0.695	0.735	0.760	0.813	0.840	0.888	0.89	0.947	0.955	0.960
50	+	0.296	0.670	1.140	1.700	2.380	3.210	4.120	5.150	6.320	7.650	10.60	14.20	18.20	22.90	28.00
	−	0.229	0.400	0.535	0.617	0.700	0.772	0.800	0.842	0.877	0.885	0.92	0.94	0.98	0.982	0.99
60	+	0.363	0.844	1.460	2.220	3.210	4.310	5.600	7.100	8.500	10.60	14.90	19.90	25.50	32.40	39.60
	−	0.266	0.459	0.590	0.689	0.772	0.812	0.840	0.887	0.920	0.915	0.955	0.98	1.00	1.00	1.00
80	+	0.515	1.240	2.260	3.530	5.120	7.120	7.220	12.00	14.90	18.20	25.8	35.3	45.00	57.00	70.00
	−	0.337	0.560	0.695	0.780	0.840	0.900	0.880	0.947	0.955	0.980	0.98	1.00	1.00	1.00	1.00
100	+	0.670	1.700	3.190	5.120	7.650	10.60	14.20	18.20	22.90	28.00	39.60	54.0	70.00	88.5	109.0
	−	0.400	0.617	0.758	0.840	0.885	0.915	0.940	0.980	0.985	0.990	1.00	1.00	1.00	1.00	1.00

TABLE 8 VELOCITY OF VIBRATIONS IN PENSTOCK

$$a = \sqrt{\frac{\frac{g}{\gamma}}{\frac{1}{e} + \frac{1}{E} \cdot \frac{D}{d}}} = \frac{22{,}720}{\sqrt{23.5 + K \cdot \frac{D}{d}}}$$

Material of Penstock	Dia. of Penstock	Thickness of Penstock Walls in in.									
		¼	⅜	½	1	1¼	1½	2	3	4	5
Steel Plate	1 ft.	3810	4160	4330	4400	4460	4530				
Cast iron		3380	3900	4100	4240	4300	4350	4430	4500		
Wood stave			2050	2400	2660	2860	3000	3250	3570	3800	
Steel plate	2 ft.	3310	3830	4040	4170	4270	4340				
Cast iron		2800	3370	3700	3900	4000	4100	4230	4380		
Wood stave				1810	2050	2230	2400	2650	3000	3250	
Steel plate	3 ft.	2950	3570	3820	4000	4100	4150				
Cast iron		2440	3050	3370	3600	3750	3900	4030	4220		
Wood stave				1520	1720	1880	2050	2300	2650	2900	
Steel plate	4 ft.	2700	3310	3600	3810	3960	4040				
Cast iron		2190	2800	3150	3390	3580	3700	3900	4100		
Wood stave				1330	1525	1680	1700	2050	2400	2650	
Steel plate	5 ft.	2530	3120	3450	3650	3830	3900				
Cast iron		2000	2600	2970	3210	3380	3520	3750	4000		
Wood stave					1380	1530	1660	1870	2200	2450	2650
Steel plate	6 ft.	2330	2950	3320	3600	3700	3850				
Cast iron			2450	2800	3050	3250	3400	3610	3900		
Wood stave					1260	1400	1520	1720	2050	2300	2510
Steel plate	7 ft.	2200	2810	3190	3410	3590	3710				
Cast iron				2650	2920	3120	3260	3500	3800		
Wood stave					1160	1300	1500	1600	1920	2160	2360
Steel plate	8 ft.	2100	2700	3060	3300	3470	3600				
Cast iron					2790	3000	3150	3380	3700		
Wood stave						1230	1330	1520	1800	2050	2230
Steel plate	9 ft.	2000	2600	2950	3200	3400	3570				
Cast iron					2650	2900	3050	3310	3600		
Wood stave						1170	1260	1450	1730	1960	2130
Steel plate	10 ft.	1920	2540	2880	3130	3310	3450				
Cast iron						2800	2980	3220	3520		
Wood stave						1120	1200	1380	1660	1880	2050
Steel plate	12 ft.	1770	2330	2700	3000	3150	3300				
Cast iron						2620	2790	3050	3380		
Wood stave						1000	1120	1260	1520	1720	1880
Steel plate	14 ft.	1660	2200	2560	2820	3000	3190				
Cast iron						2500	2650	2920	3260		
Wood stave						935	1040	1170	1490	1610	1770
Steel plate	16 ft.	1560	2100	2450	2710	2890	3060				
Cast iron						2400	2550	2800	3150		
Wood stave						875	965	1120	1330	1520	1670
Steel plate	18 ft.	1480	2000	2350	2600	2800	2950				
Cast iron							2450	2700	3050	3300	
Wood stave							900	1050	1260	1440	1590
Steel plate	20 ft.	1410	1920	2250	2520	2700	2870				
Cast iron							2330	2600	2960	3200	
Wood stave							870	990	1200	1380	1520

TOPICAL DISCUSSION ON THE PROBLEM OF SMOKE ABATEMENT

INTRODUCTORY DISCUSSION BY D. T. RANDALL[1]

The abatement of smoke from bituminous coal is an engineering problem. In choosing a coal for use in a given plant, the following points should be considered:

a The amount and character of the volatile matter
b The amount of ash and its tendency to clinker
c Moisture
d Coking and caking qualities
e Size
f Amount to be burned in a given furnace
g The kind of furnace, hand-fired or automatic
h The draft available and its regulation
i The character of the load, steady or variable
j The ability of the firemen

Most of our boiler plants were originally built to burn anthracite coal, not many being properly equipped to burn the higher volatile bituminous coals. The burning of bituminous coal is more complicated for the reason that on charging the coal upon the fuel bed, the volatile gases begin to distill off as soon as the coal is heated to the required temperature. These gases are similar in character to unpurified illuminating gas and contain tar and heavy hydro-carbons and will produce smoke unless burned under very favorable conditions. If air could be admitted in sufficient quantities and in such a manner as to mix thoroughly with these gases as they are being distilled from the coal, they could be completely burned without smoke, provided the temperature of the furnace was sufficient to ignite them. The fixed carbon, or portion of the coal corresponding to coke, remains on the grate and is burned under the conditions described for coke or other fuels containing a low percentage of volatile matter.

[1]Presented at a Boston meeting (November 1910) of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

It appears from the experiments of Dr. Horace C. Porter, of the Bureau of Mines, that coals vary considerably in the character of their volatile matter, and that their percentage as determined by proximate analysis is not necessarily a correct measure of the difficulty which may be expected in preventing smoke. The volatile matter is composed in part of inert matter such as carbon dioxide and other combinations which do not burn, and the real volatile combustible matter may be much less than appears from the ordinary coal analysis. When coals of the same general character are considered, however, the volatile matter is a very fair measure of the difficulty which may be experienced in burning them without smoke. The difference between a coal containing 16 per cent volatile matter and another one containing 21 or 22 per cent is usually noticeable when a hand-fired furnace is used. A coal containing more than 25 per cent volatile matter is difficult to burn without smoke.

If the coal contained large quantities of ash the fires must be cleaned more frequently, and in addition it is difficult to secure an even distribution of air through the bed of fuel and ash. If the ash has a low fusing point and melts and sticks to the grate, air will be shut out over portions of the grate and the difficulty of preventing smoke will increase.

An increase in the moisture in the coal usually increases the difficulty of burning it without smoke. If a coal cokes in the fire and if the draft is such as to require the frequent breaking up of the fuel bed, the coal may give off more smoke at such times than when it is fired.

The size of the coal is of considerable importance for the reason that coals which are coarse must be carried at greater depth on the grates in order to prevent an excess of air, and the finer coals must be fired very carefully in order that they may not clog the air openings through the fuel bed and thus prevent a sufficient amount of air reaching the gases from the coal. Generally speaking, coal which is fine in size must be fired in smaller quantities than coals which are in the form of lumps and records of analyses show a wide variation in coals sold for power plant purposes, the volatile matter ranging from 16 to 35 per cent, the ash from 5½ to 14 per cent, and the heating value from 13,000 to 14,600 B.t.u.

DESIGN OF FURNACES

It is evident that the design of a furnace for bituminous coal must be different from one for coke or anthracite coal. The most successful

designs provide for the admission of air to mingle with the liberated gases and also arrange some device which causes them to mix or burn before they leave the furnace, a time which probably does not exceed a second. Walls or arches are often provided which cause the gases to whirl and mix, and long or high combustion chambers are provided to allow time for the combustion to take place.

If it is found that an equipment is not satisfactory even when the most successful methods of firing are adopted, it will then in most cases be good business policy to invest in an improved type which will give practically complete combustion. There are many cases where the equipment is old and it would not be advisable to install new and expensive furnaces under an old boiler, or the power plant may be in a rented building, or for other reasons it may not be feasible to improve the furnaces. In such cases the solution must lie along the lines of choosing a coal which is best suited to the furnace which is installed. With such furnaces by mixing bituminous coal with an equal weight of anthracite screenings, quite satisfactory results may be obtained and without much difficulty from smoke. To burn such a mixture usually requires a little stronger draft than for bituminous coal alone.

In designing a combustion chamber, it is not necessarily a solution of the problem to provide a chamber of large capacity, unless it is of such a shape that the gases can be made to pass at a fairly uniform velocity over its entire cross section. A study of a great many plants seems to indicate that the distance through which the gases travel before they reach the heating surface is of more importance than the area of the passage through which they travel, for the reason that they have a tendency to travel in lines the shortest distance from the grate to the heating surface and thus to make a considerable portion of the combustion chambers merely dead spaces and inactive so far as combustion is concerned. In this connection it has been noted that the common, horizontal return tubular boiler has given very good results in comparison with other types of boilers, evidently because of the length of the travel of gases. Whenever a device is provided which tends to give a more intimate mixture of the air with the gases, it is possible to shorten the combustion chamber accordingly.

For each kind of coal and each furnace, there is apparently a range of capacity through which it is possible to operate without a serious production of smoke. At higher rates the efficiency decreases and black smoke is produced owing to a lack of furnace capacity to supply air and mix it with the gases.

The operation of firing a furnace by hand is of necessity an inter-

mittent one. Relatively large quantities of fuel must be placed on the fuel bed at one time. This fuel tends to retard the flow of air and at the same time the heat in the furnace tends to drive off the gases rapidly. Usually enough air cannot be supplied at this time and there is smoke for a minute or two after each firing, even when the stack is clear during the remainder of the time.

Hand-fired furnaces depending upon brick-work baffles, arches and piers are better than plain furnaces, and they generally decrease the smoke after the brick work is heated. Their capacity to absorb heat tends to counterbalance the gain from better combustion if a large amount of brick work is used and if the period of operation is short. A brick arch over the entire grate surface increases the rate of combustion for any given draft because it reflects heat back onto the fuel bed and assists in driving off the moisture and the volatile matter from the coal. This action may cause more volatile matter to escape than can be burned in the combustion chamber provided. In many cases more successful results in preventing smoke are obtained by omitting the arch above the grate and providing arches, piers, checkerwork, or similar construction at the bridge wall and a short distance behind it. Provisions for admitting extra air for a short period after each firing will often reduce the smoke to one-half the amount produced when only the regular supply is furnished through the grates and fuel bed. In general, furnaces based on such designs may be operated by skilled firemen with certain coals with good economy and with smoke only at short intervals after each firing or cleaning provided the rate of combustion is low.

Hand-fired furnaces properly equipped with steam jets and air admission may be operated with most coals so as to give but little black smoke except when cleaning the fires. The jet must be located so as to direct the current in the required direction to secure a rapid mixture of the gases from the coal with the air in the furnace. This often requires some experimenting. Steam jets require a large amount of steam to secure satisfactory results, but their use improves the combustion and if the methods of firing are improved when the apparatus is installed, the loss due to the use of steam may be fully or partially offset by the resulting economy. In connection with large combustion chambers or well-designed brick furnaces, fewer jets may be used or the pressure may be reduced to save steam.

In furnaces having the heating surface directly above the grate it is necessary to accomplish the admission of air by steam jets, unless sufficient air can be admitted uniformly through the grates.

A study of tests conducted at the Government fuel testing plant shows that with hand-fired furnaces the best results were obtained when the firing was done most frequently and with the smallest charges of coal. In general, coals which smoke badly give efficiencies from 3 to 6 per cent lower than coals which burn with but little smoke; also when the air supply is reduced and the furnace temperatures increased there is an increase in CO_2 and in CO which is always accompanied by smoke. In many cases there may be smoke and a considerable unaccounted-for loss when there is but little or no CO determined by the Orsat.

DESIGN OF STOKERS

These problems have led a number of inventors to design automatic stokers. With these the coal is fed in small quantities continuously in such a way as to be subjected to the heat gradually and at a comparatively low temperature and the gases are driven off mixed with air and completely burned in a combustion chamber before they reach the cooling surface of the boiler tubes. Many of these have been improved until they may be depended upon under normal conditions to burn almost any kind of bituminous coal successfully, when they are properly installed and operated. As a rule this installation included special settings and combustion chambers, depending upon the kind of boiler and of fuel to be used.

The chain grate stoker as ordinarily designed is very successful in burning high volatile and high ash coals. Under proper operation it is capable of burning such coal at high rates of combustion without smoke, and in some well-designed plants it is difficult to make these furnaces smoke even when they are improperly operated. These stokers are not adapted to burning low volatile coking coals.

Several makes of stokers on the market are designed to feed the coal from hoppers onto inclined grates, kept in motion by a driving mechanism. Some are so designed as to grind through a large portion of the ash which accumulates at the bottom of the grate. Whether this type of stoker is successful or not depends not only on its durability and resistance to the action of the heat, but also on its ability to feed the coal uniformly, heat it gradually and introduce a supply of air which will mix with and burn the gas before it has traveled far from the point at which it is liberated. Many stokers of this type are so installed and operated as to give good efficiency and smokeless combustion, but there are many others which are smoking badly.

Only within the last few years have the manufacturers of such equipment given serious consideration to the smoke problem and recognized that the stokers must be set in furnaces especially designed, with due regard to the kind of coal, boiler and service for which they are intended. It is a mistake to install these or any other stokers believing that they do not require as much or an even higher degree of skill than a hand-fired plant, provided good results are to be secured. There are two or three makes of under-feed stokers on the market. If they are so designed as to be automatic in regard to the supply of coal and air, they may be operated with very good efficiency, and when reasonable care is given to the operation, they will burn the high volatile coals with but little, if any, smoke except at the times when they are being cleaned. Owing to the fact that the air is supplied to these stokers under pressure and forced through the fuel bed, it is possible to secure an intimate mixture of the air and gases and to burn within a short distance from the fuel bed. For this reason the combustion space required is usually less than with other types of stokers. In some cases the mistake has been made of installing a stoker too small for the purpose, and the results have been unsatisfactory as the capacity of the boiler could be obtained only with difficulty, the combustion was poor and oftentimes the stack was smoky.

FURNACE EQUIPMENT

There is no other equipment in connection with a power house which requires the same degree of care and experience in its selection to secure satisfactory results as does the furnace equipment, including the design of the boiler and furnace setting. The problem of smoke abatement in power plants is by no means solved when competitive bids are secured from stoker manufacturers and an equipment contracted for, even though smokeless operation is guaranteed by the maker. The draft and the methods of regulating it with both hand and automatic stoker fired plants must always be taken into consideration. The best results are usually obtained when the draft is low because it is less difficult to maintain an even fuel bed and there is less leakage of air through holes in the setting. A great many chimneys are smoky because the draft is insufficient to supply air in the correct proportion at critical periods of operation.

Damper regulators are frequently the cause of smoke, due to the fact that they are not properly adjusted, and it often happens that firemen charge large quantities of coal into the furnace with dampers closed and no air admitted to burn these gases.

Difficulty is also experienced in preventing smoke at times when the load changes rapidly, or when the boilers are heavily overloaded. Oftentimes the furnaces will smoke when boilers are cut out and banked, and they are equally liable to smoke when they are being brought from a banked condition into service.

It is very difficult to start a fresh fire with bituminous coal under a boiler without producing smoke. In cities where there is a smoke ordinance it is quite often the practice to start fresh fires before the smoke inspector is on duty. This problem is being met at the present in some boiler plants, in foundry cupolas and other industrial furnaces, by using a bed of coke, ignited by means of a gas or oil flame from a portable burner installed for the purpose. Such a procedure will build up a fuel bed and bring the furnace walls up to a temperature so that fresh coal may be fired without particular difficulty. This plan is of course more expensive and more troublesome than to start the fire with some kindling and bituminous coal as has been the custom for a long time.

Furnaces may be grouped as follows:

a With iron-enclosed combustion chamber and short gas travel, such as house-heating boilers, internal fire-box boilers, and vertical boilers not provided with extension furnaces.

b With brick side walls, small combustion chambers and short gas travel, such as water-tube boilers with grates directly below the heating surface.

c With iron surfaces of boilers forming roof of combustion chamber, and long gas travel, such as horizontal return tubular, Heine type, etc.

d With brick-enclosed combustion chamber and long gas travel, with special arches, piers, etc., to aid in mixing air and gases.

e With any one of the above types and further equipped with automatic steam jets and air admission.

f With any one of the above types equipped with automatic stokers.

DESCRIPTION OF TESTS

To illustrate the variations in conditions under which coal is being burned, tests were made, and are herewith tabulated in Tables 1 to 7.

The observations in Table 1 were made at an electric light plant on B. & W., boilers, rated at 350 h.p. each. These boilers were set at a height to give about 42 in. between the grate and tubes of the boiler.

TABLE 1 TEST ON B. & W. BOILERS

Time	Draft Back of Boiler	Thickness of Fire	Gas Analyses Per Cent by Volume			Remarks
			CO_2	O_2	CO	
4.03	....	18	....	...	...	Fired 14 shovels coal
4.07	0.10	18	13.6	1.5	2.3	4 min. after firing
4.20	....	18	....	...	...	Fired 15 shovels
4.25	0.11	17	12.5	1.1	3.5	5 min. after firing
4.37	....	18	....	...	...	Fired 14 shovels
4.42	....	18	....	...	...	Raked fire
4.45	0.21	18	13.7	1.0	6.7	3 min. after raking
5.05	....	18	....	...	...	Fired 15 shovels
5.15	0.25	18	18.2	0.6	1.0	10 min. after firing
5.33	....	18	....	...	...	Fired 16 shovels
5.35	0.20	18	15.3	1.0	3.6	2 min. after firing
5.55	....	....	....	...	...	Fired 17 shovels
5.58	0.08	19	12.0	0.3	4.7	3 min. after firing

TABLE 1a SPECIAL DRAFT READINGS TO SHOW ACTION OF DAMPER REGULATOR

Time	Draft at Outlet from Boiler	Remarks
p.m.		
6.25	0.06	Damper closed
6.26	0.35	Damper half closed
6.27	0.07	Damper closed
6.30	0.42	Damper open
6.32	0.46	Damper open

It will be seen from the analyses that when several shovelsful of coal are fired at one time, large amounts of carbon monoxid and unburned gas escape from the furnace and that there is also a considerable loss after long intervals if the damper was nearly closed. The stack smoked almost continuously during this period and the smoke was more than 60 per cent black for periods of four or five minutes after each firing. These readings in this table indicate the frequency of changes in the draft due to the action of the damper regulator. Such changes are unfavorable to good combustion. A damper regulator in perfect working order should not permit of such fluctuations in draft. The analysis of coal burned at this plant was as follows:

Moisture	2.69
Volatile	16.30
Fixed carbon	73.99
Ash	6.92
	100.00
Sulphur	0.61
B.t.u.	14,207

These results indicate that the conditions under which the coal was burned were very unfavorable, that the fire was too thick, that too much coal was fired at one time, and that the draft was not properly regulated. The combustion chamber is small and the gases pass directly from the fuel bed to the boiler tubes with but little opportunity to mix the gases from different parts of the grate. With such a furnace it is possible to have too little air on one side and too much air on another. Frequently there will be incomplete combustion and an excess of air at the same time.

TABLE 2 TESTS ON A CLIMAX BOILER

Time		Draft over In. of Water	Steam Pressure	Flue Temp. Deg. Fahr.	Gas Analyses Per Cent by Volume				Air Excess Per Cent
From	To				CO_2	O	CO	N	
a.m.	a.m.								
9.00	9.30	0.11	99	565	12.6	6.2	0.0	81.2	41
9.30	10.00	0.13	98	565	13.8	4.6	0.1	81.5	27
10.00	10.30	0.12	101	595	14.6	4.0	0.2	81.2	23
10.30	11.00	0.11	99	575	14.9	3.9	0.1	81.1	23
11.00	11.30	0.17	97	545	12.6	6.6	0.0	80.8	45
11.30	11.58	0.11	97*	540	13.4	5.5	0.0	81.1	35
p.m.	p.m.								
1.30	2.00	0.17	98	595	12.5	6.3	0.1	81.1	42
2.00	2.30	0.15	100	535	13.7	5.5	0.0	80.8	35
2.30	3.00	0.21	97	535	13.4	5.7	0.0	80.9	37
3.00	3.30	0.18	97	565	11.5	8.0	0.0	80.5	61
3.30	4.00	0.19	98	575	12.9	6.5	0.0	80.6	44
4.00	4.30	0.21	97	570	14.3	4.8	0.1	80.8	29
4.30	5.00	0.17	98	560	14.2	4.9	0.0	80.9	30
5.00	5.30	0.16	99	545	14.5	4.3	0.0	81.2	25
5.30	5.55	0.28	..*	545	14.4	4.7	0.3	80.6	29
Average		0.16	98	560	13.6	5.4	0.1	80.9	35

*Hand damper dropped.

The results in Table 2 were obtained on a Climax boiler, rated at 800 h.p. This boiler was provided with a plain grate, having 125 sq. ft. of surface. The distance between the grate and the boiler tubes was $3\frac{1}{2}$ ft.; the tubes being directly over the fire. The rate of

combustion was low, being approximately 12 lb. of dry coal per sq. ft. of grate. The coal used was of the character shown by the following analysis:

Moisture	2.12
Volatile	16.38
Fixed carbon	75.47
Ash	6.03
	100.00
Sulphur	1.03
B.t.u.	14,431

This furnace is open to the same criticism as that in Table 1, but the results are good because of exceptionally good firing.

TABLE 3 RECORD ON HORIZONTAL RETURN TUBULAR BOILER

Time	Min. after Firing	Coal Fired Shovels	Thickness I.	Draft Furnace	Draft Outlet	Gas Analyses Per Cent by Volume			Remarks
						CO_2	O_2	CO	
10.40	..	8	10	....	....	....	....	....	No smoke
10.45	5	..	..	0.25	0.47	11.6	8.2	0.0	.....
10.51	..	7	10	....	....	....	....	....	No smoke
11.00	9	..	..	0.26	0.50	13.8	6.4	0.0	.....
11.05	..	9	10	....	....	....	....	....	No smoke
11.13	..	..	..	....	....	....	....	....	Raked fire Trace smoke
11.15	10	..	11	0.25	0.48	13.5	5.8	0.3	.....
11.17	..	8	10	....	....	....	....	....	10% smoke ½ minute
11.23	..	8	11	....	....	....	....	....	10% smoke ½ minute
11.30	7	..	..	0.24	0.48	13.2	6.6	0.0	.....

Note.—When fire is loosened by bar, smoke as high as 60 per cent is given off for about ½ minute and an average of about 20 per cent for two minutes after.

There were four furnace doors equally spaced around the circumference of the furnace. Coal was fired in quantities of about five shovelsful at a time and at regular intervals. At times just after firing there would be a very thin smoke at the top of the stack. In many cases there was no smoke. On two or three occasions the smoke reached a density of 40 per cent for a period of about one-half minute after firing. This plant was practically smokeless except at times when the fires were banked or when they were broken up after having been banked and when cleaning the fires. It was only for a very short period of time that the smoke was darker than 60 per cent black. This plant smoked about 40 per cent black for one-half minute after firing

when the coal is very wet. Full capacity could not be carried without smoking seriously.

The behavior of the same coal in another plant under a return tubular boiler is shown in Table 3. The boiler was provided with a rocking grate having an area of 36 sq. ft. The fireman was not a highly trained one, but the fires were maintained in good condition and there was practically no somke during the periods of regular operation. The load was nearly constant. This furnace has a long combustion chamber and is not nearly so sensitive to changes in the thickness of the fire or the amount of coal charged at one time as the furnaces described under Tables 1 and 2.

The observations in Table 4 were taken on a 225-h.p. vertical fire-tube boiler of the Manning type, having a grate surface of 41½ sq. ft. and provided with two firing doors and eight steam jets. The dis-

TABLE 4 GAS SAMPLES TAKEN AT POINT WHERE FLUE GASES LEAVE BOILER ROOM

Time*	CO_2	O_2	CO	N_2	Draft, In. of Water		Flue Temp.
					Over Fire	In Flue	
1.00	12.0	8.0	0	80.0	0.30	0.40	470
1.20	11.0	7.9	0	81.1	0.35	0.35	480
1.40	11.8	7.7	0	80.5	0.30	0.30	470
2.00	10.2	9.3	0	80.5	0.30	0.40	490
2.20	11.2	8.3	0	80.5	0.30	0.35	490
....†	12.6	6.2	0.8	80.4	....	....	...
....	12.6	6.6	0.6	80.2	....	....	...
....	11.9	7.4	0.9	79.8	0.25	0.30	490
....	13.5	5.4	0.6	80.5	....	....	...

* Steam jets in operation. † Steam jet off.

tance from the grates to the heating surface is 6 ft. This furnace is similar to those in Tables 1 and 2 and can not be operated at full capacity without smoke unless steam jets are used. The coal burned showed the following composition:

Moisture	1.87
Volatile	18.18
Fixed carbon	73.55
Ash	6.40
	100.00
Sulphur	0.63
B.t.u.	14,538

Each steam jet draws in a quantity of air through a pipe which surrounds it. Provision is made to regulate the amount of air supplied with the steam. These steam jets are located about 3½ ft. above the grate surface. The thickness of fire is maintained at about 12 in. and the fuel bed is kept as level as possible. Coal is charged in quantities of 8 or 9 shovelsful at a time through one door of the furnace. At intervals of about 8 or 10 minutes, depending upon the load, the other door is charged with a similar quantity of coal. The rate of combustion is about 20 lb. of coal per sq. ft. of grate.

TABLE 5 TESTS ON PLANT HAVING HORIZONTAL RETURN TUBULAR AND STIRLING BOILERS

Time	After Firing	Damper had been Closed or Open	Position of Damper	Draft, In. of Water		Flue Temp. Deg. Fahr.	Gas Analyses Per Cent by Volume				Air Excess Per Cent
				Over fire	In Flue		CO_2	O	CO	N	
STIRLING BOILER											
10.40	4	1	Closed	0.04	0.05	480	12.7	0.9	7.0	79.4	5
10.55	2	9	Open	0.03	0.04	455	13.4	0.5	4.9	81.2	3
11.10	10	24	Open	0.11	0.16	445	7.1	12.1	0.8	80.0	136
1.05	2	5	Closed	0.03	0.04	445	16.2	0.6	0.8	82.4	3
1.20	6	11	Open	0.17	0.26	455	5.5	14.9	0.0	79.6	248
1.35	2	1	Closed	0.03	0.04	420	13.0	1.0	4.6	81.4	5
1.50	8	3	Open	0.09	0.12	420	8.8	9.9	1.9	79.4	90
2.05	5	18	Open	0.08	0.11	410	10.1	8.3	1.4	80.2	65
Average				0.07	0.10	440	10.8	6.0	2.7	80.5	69
HORIZONTAL RETURN TUBULAR											
2.30	5	43	Open	0.16	0.23	455	11.5	8.5	0.0	80.0	68
2.45	0.05	58	Open	0.09	0.13	450	13.4	7.0	0.0	79.6	50
3.00	0.05	73	Open	0.15	0.21	475	13.3	5.5	0.0	81.2	35
3.15*	2	88	Open	0.13	0.19	500	15.0	3.8	0.4	80.8	22
3.30	2	103	Open	0.15	0.22	490	12.6	7.2	0.0	80.2	52
3.45	12	9	Closed	0.14	0.20	450	11.6	8.8	0.0	79.6	73
4.00	7	24	Closed	0.13	0.17	460	12.1	8.0	0.0	79.9	62
Average				0.14	0.19	470	12.8	7.0	0.1	80.1	52

	Stirling	Horizontal Return Tubular
Average thickness of fire, in.	11	9
Average weight of coal fired each time, lb.	65	55
Average interval between firings, min.	9	7
Intervals between firings vary		
from, min.	3	2
to, min.	18	16
Per cent of time damper		
open.	60	80
closed.	40	20
Lb. of coal burned per sq. ft. of grate surface per hr.	10.3	14.5

*Sliced fire 3.14½

To determine the effect of the steam jets, observations were taken with and without them.

With the steam jets on there was practically no smoke issuing from the top of the stack and it would be classed as a smokeless plant. Without the steam jets, it will be noted that there was considerable unburned gas and there was smoke varying from No. 1 to No. 3, Ringelmann's chart. While this would not be classed as a dense black smoke, and would not be subject to a fine under most city ordinances, it would indicate that a little carelessness on the part of the fireman would without doubt cause dense smoke and subject the plant to fines.

The observations in Table 5 were taken in a boiler plant burning coal which analyzed as follows:

Moisture	3.38
Volatile	20.32
Fixed carbon	66.94
Ash	9.36
	100.00
Sulphur	2.22
B.t.u.	13,528

The plant was equipped with a 150-h.p. horizontal return tubular boiler having 33 sq. ft. of grate area, and a Stirling boiler rated at 225 h.p., having a grate area of 48 sq. ft. The draft was regulated by means of a damper regulator operating on individual dampers on each of the boilers.

TABLE 6 B. & W. TYPE BOILER HAND-FIRED

Time	Draft		Temperature Flue Gas	Thickness of Fire, In.	Shovels Fired	Min. after Firing	CO_2	O_2	CO
	Furnace	Boiler							
2.20	0.37	0.46	675	5	18	..	..	..	..
2.25	..	..	765	..	..	5	7.5	11.9	0
3.00	0.36	0.47	725	5	16	..	..	..	..
3.04	..	..	745	..	..	4	7.3	12.0	0
3.25	0.37	0.48	680	6	17	..	..	..	..
3.27	..	..	..	..	..	2	8.1	9.6	1.2

Note.—This plant smoked 100 per cent black for about 2 minutes after each firing, and did not clear up for 5 or 6 minutes. Average period between firings about 10 minutes.

During the time the observations were taken on the Stirling boiler the load was light and the damper was closed most of the time. The stack smoked badly during this period. During the period of observations on the horizontal return boiler the greater part of the load was placed on it. A higher rate of combustion was maintained and

economical operating conditions resulted. It is probable if this boiler had been operating alone that the amount of smoke would have been greatly reduced.

It will be noted that the damper on the horizontal return tubular boiler did not close sufficiently to reduce the draft. The method of firing in this plant was very poor; there was too much coal fired at one time and the intervals between firings varied from 2 to 18 minutes. This is too great a variation. The firemen paid no attention to the position of the dampers and coal was charged in large quantities when the damper was closed. This coal on being heated gave up its volatile gases, a large part of which passed to the stack without burning on account of the limited supply of air, due to low draft. This of course caused dense smoke and an enormous fuel loss. The calculated loss due to carbon monoxid in the flue gases from the Stirling boiler amounted to approximately 11.5 per cent.

The observations in Table 6 were made on a B. & W. boiler rated at 200 h.p., provided with rocking grates 6 ft. by 6 ft. Coal was burned at an average of 18 lb. per sq. ft. of grate.

It was the practice of the firemen to charge a large quantity of coal at one time and to allow the bed of fire to burn low before firing again. This practice is bad in any case, but with the high volatile coal burned, the results show a very poor economy. The plant smoked badly after each firing. The coal used was of the following composition:

Moisture	1.55
Volatile	31.11
Fixed carbon	55.55
Ash	11.29
	100.00
Sulphur	2.69
B.t.u.	13,324

These examples serve to emphasize the importance of favorable kinds of coal, careful firing and large combustion chambers. Many others might be given but these represent typical cases and indicate how inefficiently most of the boiler plants are being operated. On the other hand it will be observed that with careful firing results are obtained which compare favorably with plants in which automatic stokers are being carefully operated. The best results were obtained with plants burning low volatile, low ash coals, and with loads which were practically constant, and usually below the rated capacity of the

TABLE 7 RESULTS TAKEN FROM U. S. GEOLOGICAL BULLETIN

No.	Special Device	Design Furnace	Coal	Size	Coal per Sq. Ft.	Kind of Boiler	Per cent Smoke	Above 60% Min. per Hr.	Remarks
216	Steam Jet	Plain	..	Screenings	..	B. & W. Type	..	0	Six ¼" steam jets. Smokes 10 to 20% for ½ min. Success due to careful operation.
227	None	Corrugated Flue	..	R.o.m.	9.5	Scotch Marine Type	4.2	0	Air admission at bridge wall.
240	Steam Jet	Plain	W. Va.	R.o.m.	12.7	Stirling	3.0	0	Steam jets continuous. Twenty ¼" jets to furnace.
215	Steam Jet	Dutch Oven	W. Va.	Slack	17.1	B. & W. Type	..	0	Eight ¼" steam jets to each furnace. Observations include some 10, 20 and 40% readings.
231	None	Dutch Oven	Ill. W.	Fine	25.0	Water Tube	12.6	13	Large combustion chambers. Furnace doors cracked after firing.
217	None	Dutch Oven	..	Slack	12.5	B. & W. Type	5.7	0	Usually burn half anthracite to keep down smoke.
218	None	Brick Furnace	Ill.W.	Fine	32.1	Heine Type	5.3	3	Dorrance design. Total length of brickwork over furnace 11.25 ft.
233	None	Brick Furnace	Ill.	Nut	27.0	B. & W. Type	0	0	Long sloping brick arch (Dorrance).
221	None	Down Draft	W.Va.	Screenings	..	Heine Type	..	0	When coal is fired. Occasionally on lower grate, smokes 40 to 60% about 1 minute.
226	None	Down Draft	Ind.	Screenings	31.0	Scotch Marine Type	7.9	4	Ash pit doors opened a little.
225	None	Coking Furnace	Ill.W.	Nut	10.0	Scotch Marine Type	..	..	Burke design. Stack clear except for short time after cleaning, 40 to 60% black smoke.
237	None	Coking Furnace	Ind.	R.o.m.	24.0	Stirling	0	0	Burke design. Large coking capacity.
255	Steam Jet	Plain	Ohio	R.o.m.	14.7	H.r.t.	1.3	0	Arch in combustion chamber. 12 automatic steam jets on 5 or 6 minutes at each firing.
262	Steam	Plain	W.Va.	R.o.m.	14.0	H.r.t.	0.1	0	Large combustion chamber. Jets not automatic. Careful firing.
263	None	Plain	W.Va.	R.o.m.	13.0	H.r.t.	..	0	Large coal. Special brickwork on bridge wall. Less than 20% smoke 1 min. after firing.
265	None	Plain	W.Va.	Screenings	11.5	H.r.t.	..	0	Smoke observations include some 10, 20 and 40% readings.
266	None	Plain	W.Va.	Slack	13.5	H.r.t.	..	0	Coal cokes and requires frequent poking. Smokes 60% and less about 1 minute after each firing.

boilers. It is demonstrated that plain hand-fired furnaces may under very favorable circumstances be operated without smoke, but that under ordinary conditions they will be inefficient and smoky.

The results in Table 7 are from U. S. Geological Survey Bulletin 373. During the investigations of smokeless plants it was noted that very few plants were being fired by hand without smoke unless steam jets were used for at least a minute or two after each firing. Some plants were doing fairly well without steam jets, but they were in many cases burning large-sized coal and admitting an excess of air, or they were operating at low capacity. Some of the better operated plants were not smokeless but the stacks smoked only for one or two minutes after each firing, beginning with a density of about 60 per cent black and diminishing to about 20 per cent at the end of a half minute. Such plants are not usually subject to fines.

GENERAL DEDUCTIONS

General deductions may be drawn as follows:

a Plain hand-fired boilers may be operated with but little smoke with low volatile coals, or in some cases, with other coals if the rate of combustion is low.

b Hand-fired furnaces with brick arches, etc., are more easily operated without smoke than the plain furnaces.

c Almost any hand-fired furnace may be operated by means of steam jets so as to produce but little smoke.

d While all of the above may be accomplished with a skilled fireman, such plants cannot be depended upon for smokeless results at all times.

e Stokers without suitable combustion chambers or when improperly operated may be expected to smoke.

f Experience has demonstrated that the best stokers properly installed are superior to hand-fired furnaces for economy and smokelessness.

As will be seen from these results, it is possible to burn low volatile and low ash coals with nearly the same efficiency at moderate rates of combustion as may be expected with mechanical stokers when operated by firemen equally skilled. This condition makes it difficult to induce the owners of small plants to install stokers unless they do so for the purpose of reducing the smoke. In a large plant the expense of installing stokers is fully justified because of the saving in fuel and labor. They may in a sense be considered as part of the coal-handling

machinery. The large plant has the benefit of the best engineering talent in the design and construction, and of expert engineering advice and supervision throughout its period of operation. The economy in handling coal and ash, the economy due to a higher order of supervision made possible by the size of the plant, the reduction of labor, and the advantage of buying supplies in large quantities, reduce the cost of power. Incidentally, the plant may be operated with less smoke than a number of small units of the same horsepower located in individual plants.

The average business man does not maintain a power plant from choice but from necessity. If he were able to purchase heat as well as light and power he would gladly pay for service from a central station. This would relieve him of the main details connected with the management of his steam plant and would give him the space occupied by the plant for use in his regular line of business.

The growth of the central heating business has been rapid during the past five years in some localities, and there seems to be a tendency on the part of manufacturers and merchants to purchase heat in case it can be obtained at or near the figure which it costs them to produce it.

It is perfectly logical to expect a reduction of smoke within a few years due to the adoption of systematic plans for numerous heating and lighting stations so distributed in each large city as to serve the business districts with light, power and heat economically. These stations could probably be most economically operated if they generated only enough steam for heating and were arranged as sub-stations to take excess electric current required from a central power house so located as to generate current at the lowest cost.

COMCLUSIONS

The smoke from power plants may be greatly reduced by adopting the following methods:

a Use low volatile coals or mixtures of bituminous coal with coke or anthracite in all hand-fired furnaces. Use steam jets if necessary to prevent smoke at high rates of combustion.

b Use automatic stokers in all plants in which the expense can be offset by the saving due to better combustion, a reduction of labor and the use of cheaper fuel.

c Build central plants for heat, light and power to replace the numerous small boiler plants in the business districts of our cities.

FURTHER DISCUSSION

E. G. Bailey. Although the Ringelmann smoke chart has been used for many years as a standard of measurement, it has only recently received the attention which itdeserves. The error caused by the personal factor of the observer, which is much smaller than is generally believed, is due to the color of the smoke being sometimes of a brownish cast as compared with the jet black ink used in making the charts. It must be remembered that smoke corresponding to

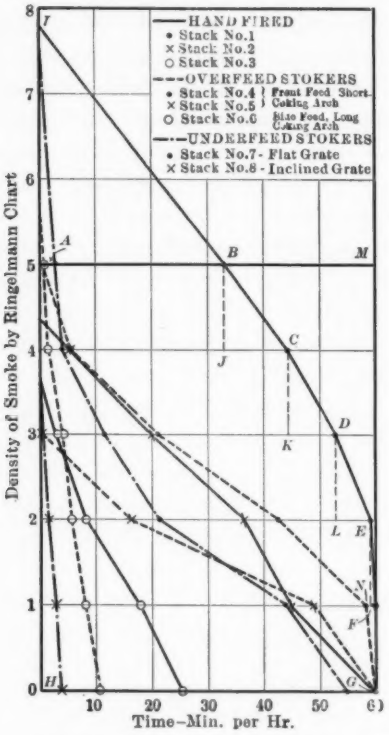


Fig. 1 Plot of Observations Given in Table 8

No. 1 must allow 80 per cent of light to pass through it; No. 4 passes 20 per cent of light; No. 5 is opaque regardless of exact matching of color shades.

When comparing smoke with the chart, the density of smoke should be as dense or denser than the number assigned it, yet not so dense as the next higher number. For instance, if smoke is denser

than No. 3, and not so dense as No. 4, it should be recorded as No. 3. Likewise, if smoke being emitted from a stack is not so dense as No. 1, it should be recorded as − 1 or + 0. The density of the smoke is obtained by averaging all readings and expressing the result in percentage of smoke on the basis of No. 5 being 100 per cent, but this method gives very little idea of the nature of the smoke. Ringelmann chart readings are usually taken at ½-min. or 1-min. intervals during the period of an hour or more and the readings plotted in the form of a log. The plotted continuous log gives a very good general idea of the manner and regularity of the smoke emission, but it is very unsatisfactory for comparing one stack with another, or the same stack from time to time.

An additional method which the writer has used to good advantage for several years is to plot a series of readings as one characteristic curve. This is done by adding the total number of readings of each different density and reducing them to a basis of minutes per hour. To the number of minutes corresponding to each density is added all the minutes corresponding to the greater densities and plotting Ringelmann chart numbers as ordinates, and minutes as abscissae. For example, in Fig. 1, stack 7, the readings of a 2-hr. period reduced to minutes per hour were as shown in Table 8.

TABLE 8 SMOKE OBSERVATIONS—STACK 7

Density, Ringelmann Chart No.	Smoke of Each Density Emitted, Min.	Smoke of Each Density and Darker Emitted, Min.
5	2.5	2.5
4	1.0	3.5
3	8.0	11.5
2	9.5	21.0
1	23.0	44.0
−1+0	10.5	54.5
0	5.5	60.0
	Total 60.0	

The values in the last column are plotted as abscissae on the lines corresponding to the different density numbers, and the curve drawn through these points indicates the general character of the smoke being emitted.

The curves in Fig. 1 represent a variety of plants located in different places with various equipment, but all burning semi-bituminous coal with volatile matter between 17 and 21 per cent. Most of these data

were obtained in connection with the drafting of the smoke bill recently enacted for Boston through the effort of the Fuel Supply Committee of the Boston Chamber of Commerce. Detailed information relative to the rate of combustion, number of boilers in operation, flue gas analysis, etc., is lacking in these cases, but they are given to show the different characteristics of different equipment and operating conditions.

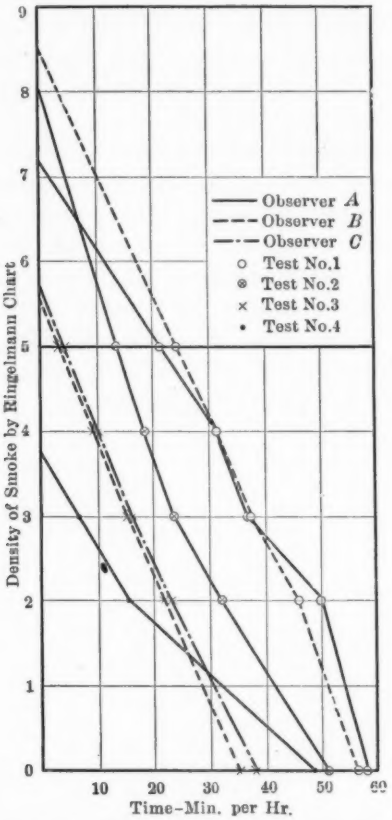


FIG. 2 CHARACTERISTIC SMOKE CURVES FROM INTERNALLY FIRED BOILER

Stacks 1, 2 and 3 (Fig. 1) are connected with hand-fired boilers, and the curves show the same general rate of gradation, but there is a great difference in the total amount of smoke produced from each. Stack 1 emitted No. 5 smoke for 33 min.; No. 4 smoke and darker, 44½ min.; No. 3 smoke and darker, 53 min.; No. 2 smoke and darker, 59½ min.; and No. 1 smoke and darker, 60 min. per hr. No. 5 on the

Ringelmann chart includes all smoke that is opaque, and for a stack of a given diameter a certain amount of carbon particles per cubic foot is necessary to make this smoke opaque, but twice as much carbon or smoke could be carried per cubic foot of gas without changing the readings. This point is graphically brought out in these characteristic smoke curves. For instance, stack 1 would not be likely to produce smoke of No. 5 density, no more or no less, for 33 min. out of 1 hr., but during a part of this time it is undoubtedly much denser, as indicated by projecting the curve back until it intercepts the zero line at a density of eight. The exact nature of the extended

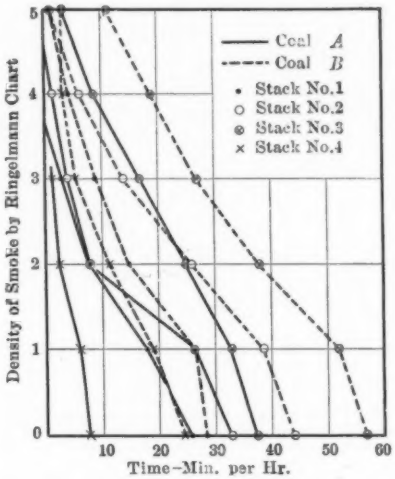


FIG. 3 SMOKE EMITTED FROM FOUR DIFFERENT STACKS ON TWO 11-HR. TESTS

part of this curve is problematical, but it illustrates the point that the average density of smoke may be much greater than is indicated by merely averaging the readings in the usual method. The average density of smoke, as compared with No. 5 by the Ringelmann chart as a basis, is the area *HIBEG* divided by *AMGH*, or 103 per cent.

If the area representing smoke denser than No. 5 is neglected, we have area *ABEGH* divided by *AMGH*, or 87.8 per cent. If the usual method of averaging smoke readings, such as was apparently used in the U. S. Geological Survey Bulletin No. 373, be applied to this stack we get only 83.3 per cent. This error is due to the omission of the triangular areas *BJC*, *CKD*, *DLE* and *ENF*, which properly belong in the area representing the total smoke emitted. All of the No. 4 readings representing the $11\frac{1}{2}$ min. from *J* to *C*, were as dense

as, or denser than, No. 4, and less than No. 5, so they would naturally be distributed along the diagonal line *BC*, and the same holds true with respect to the other parts of the curve. Applying the averaging method to the curve representing stack 5 (Fig. 1), 21.8 per cent of smoke is obtained, while the true average from the area is 31.8 per cent. The flatter the curve, the greater is the error caused by the use of the averaging method as usually applied, and the result is always too low.

Stacks 4, 5 and 6 are connected with stoker furnaces of the overfeed type, the first two having short coking arches with front-feed. The plants are similar with respect to the number of boilers and size

TABLE 9 GENERAL DIMENSIONS AND EQUIPMENT OF EACH STACK

Stack	Stack Diameter, Ft.	Number of Boilers Connected	Type of Boilers	Total Rated Boiler H.P.	Total Grate Area Sq. Ft.	Method of Firing
1	8	6	h.r.t.	900	204	hand-spreading
2	7½	8	h.r.t.	1200	272	hand-spreading
3	4	1	porcupine	300	56	hand-spreading
4	7	7		1050	235	hand-spreading

of stack, but the relative rates of combustion, volatile matter in coal, etc., are not known. Stack 6 had only one furnace of side-feed type with a long coking arch connected with it.

Stacks 7 and 8 are connected with under-feed stoker No. 7, having five stokers with flat grates, and stack 8, having three stokers of the inclined grate type.

No specific conclusions as to the value of the different methods of firing should be drawn from the curves in Fig. 1, since they are merely given to show the great variation that exists in actual practice between plants with similar equipment.

The characteristic smoke curves in Fig. 2 were all taken from the same stack connected with an internally-fired boiler of the locomotive type. The same kind of coal was fired by the same fireman, using the spreading method, in each test. The only changes made on the different tests were in the amount and temperature of secondary air supply. The coal used on these tests contained about 30 per cent of volatile matter, and over 50 lb. of it were burned per square foot of grate per hour.

The agreement between different observers is shown in Tests 1 and 3. Observers *A* and *C* had had very little experience in the use of

the Ringelmann chart, and neither knew that observer *B* was taking readings.

The curves in Fig. 3 represent the smoke emitted from four different stacks at one plant on two 11-hr. tests made on consecutive

TABLE 10 GENERAL DATA REGARDING SMOKE PRODUCED

		A	*B*
a	Coal fired		
b	Analysis of coal	Per cent	
	(1) moisture	4.81	5.40
	(2) volatile	16.22	18.81
	(3) fixed carbon	70.40	69.00
	(4) ash	8.57	6.97
	(5) sulphur	1.20	0.70
c	B.t.u.	13,639	13,838
d	Average draft in firebox		
	Boilers of Stack	In. of Water	
	1	0.45	0.32
	2	0.25	0.31
	3	0.30	0.32
	4	0.21	0.27
e	Coal fired per sq. ft. grate per hr.	Lb.	
	1	15.1	13.8
	2	11.9	11.8
	3	19.6	16.5
	4	9.2	11.7
f	Flue gas analysis CO_2	Per cent CO_2 Volume	
	1	8.1	7.7
	2	6.9	7.4
	4	7.4	9.5
g	Flue gas analysis CO	Per cent CO Volume	
	1	....	....
	2	....	0.05
	4	....	0.20
h	Air excess from flue gas analysis	Per cent	
	1	137.0	146.0
	2	180.0	149.0
	4	155.0	87.0
i	Smoke with No. 5 on Ringelmann chart as 100 per cent, from Fig. 3.		
	1	13.8	22.8
	2	18.2	35.8
	3	34.7	56.0
	4	4.3	17.2

days. The tests were primarily made to determine the comparative values of the different coals from the evaporation on the entire plant, and the firemen gave no attention whatever to the amount of smoke made.

Table 9 gives the general dimensions and equipment connected with each stack, and Table 10, the general data which have direct bearing on the amount of smoke produced. All conditions were maintained as nearly uniform on the two tests as the daily operation of the plant would permit, the only intended change being in the coal burned. The principal difference between the coals so far as smoke was concerned is in the percentage of volatile matter, which was 16.22 and 18.81 in coals *A* and *B* respectively as fired, or 17.04 per cent and 19.88 per cent on the dry basis. Owing to changes in the draft and the amount of clinker formed, the rate of combustion was not quite the same for the two tests. There was also some change in the flue gas analysis and air excess. The gas samples were taken from the main flues and included considerable leakage of air through the boiler settings. No gas analysis was made from stack 3.

The curves in Fig. 3, and i derived from them, indicate very clearly the increased amount of smoke due to an increase of 2.8 per cent in the volatile matter. The increase in smoke from stacks 1 and 3 was proportionally less as compared with the increase from stack 2, owing to the lower rate of combustion in stacks 1 and 3 with coal *B*, as compared with coal *A*, while the rate was practically the same for both coals in stack 2. The amount of smoke from stack 4 was four times as much with coal *B* as with coal *A*, due to an increase in the volatile matter of the coal, rate of combustion and decrease in the excess of air.

Slight differences in the percentage of volatile matter, rate of combustion, air excess, method of firing, etc., are found to have a marked effect upon the amount of smoke produced when the characteristic curves are drawn. By the use of such data and curves, it is possible to determine the relative importance of the different factors affecting this problem, and to take intelligent steps to reduce the density of smoke to the desired limits.

The time and density limits incorporated in the law for the abatement of smoke recently enacted for Boston and its vicinity have been worked out along this line and are possible of attainment in everyday practice if the conditions of individual plants are properly studied and changes intelligently made.

FREDERIC H. KEYES said that the power plants of New England are so situated that the use of anything but bituminous coal is impossible; and unfortunately the price is usually the controlling factor rather than the quality, a fact largely responsible for the amount of smoke. Some of the largest users of bituminous coal have already found it advantageous to buy their coal under specifications especially drawn up to meet their requirements. This would seem to be the first step in the right direction, so far as smoke is concerned. The next step is to fire and burn it properly. Here the coöperation of the fireman is absolutely necessary. If he could be induced to regard the problem from the standpoint of the man who pays the bills the results would be entirely satisfactory. From personal experience and observation he knew that in plants where a good system of firing was followed, satisfactory results were obtained with a reasonable amount of supervision and without any other special devices. Next to the fireman the quantity of air, together with the manner and conditions under which it is mixed with the products of combustion, is of the greatest importance. This is a point which must be determined for each individual case according to the kind of coal used and the general conditions governing the operation of the plant. It is a fact that under favorable conditions a good grade of bituminous coal can be burned without making smoke, and under other conditions the results are satisfactory if mixed with anthracite screenings or coke breeze. It is believed that special devices such as steam jets and fire-brick arches, with few exceptions, usually cost more to operate and maintain than can be saved through the use of low grade fuel, for which some such special device is almost always required in order to obtain even approximately satisfactory results. While it is believed that greater care in the purchase of coal and the setting of boilers will accomplish much in the way of preventing smoke, more can undoubtedly be done by educating the fireman to the proper use of the fuel given him.

CHARLES H. MANNING. The use of under-feed stokers deserves more consideration than Mr. Randall gives it, not so much for smoke prevention as for economy. Such stokers heat the fuel slowly and the hydro-carbons are gradually gasified, which allows of their combustion as they pass up through the incandescent layer of fuel above them; whereas in hand-firing they flash into gas as the coal is thrown on top of the fire, and pass off largely unconsumed, increasing the smoke. It is true that these stokers are used to less advantage in

power plants running intermittently since they smoke when the furnace door is opened during the last hour of the run to break down the fire.

It is believed that with hand-firing the fixed carbon is a better guide to the value of the fuel than the British thermal units, which is a useful guide, however, for under-feed stokers.

HENRY BARTLETT. I wish to speak of the problem of smoke abatement from the standpoint of the railroad man, giving some of the reasons for making smoke, the difficulties in mitigating it, and some of the remedies applied.

We have in the locomotive itself an overworked power plant. The boiler is restricted in dimensions, operated under forced draft at all times and compelled to burn 100 lb. or more of coal per square foot of grate per hour as compared with the stationary plants burning 10 or 20 lb. The locomotive boiler is called upon for ranges of work greater than that of any other service. One moment the locomotive may be quietly standing in the roundhouse with the banked fire and only 40 or 50 lb. of steam on the boiler, and within an hour it may be running on the road with its 200 lb. of steam and exerting its maximum power. It may be moving along and handling its heavy train, emitting little smoke, when the next moment it is suddenly stopped by a signal or flag, or required to take a siding to meet an opposite train. Under such changes it is impossible to eliminate the smoke, since the large body of coal necessary to perform the work keeps on emitting the volatile gases until they have disappeared. The terminals of runs are necessarily in large cities and here the locomotives are housed and have their fires cleaned and built up, all of which involves dirt and smoke. For these reasons it is impossible to burn bituminous coal in locomotive service without some smoke.

The only smokeless fuels available are anthracite coal, coke and oil. Should the railroads resort to the use of the first, the supply would be insufficient, since Pennsylvania mines only 70,000,000 tons annually, or less than the amount of coal consumed by the locomotives per year, and secondly, the price would so advance as to render the cost prohibitive. While coke is smokeless, that is its principal claim for merit, since on account of its other qualities, it has only about 80 per cent of the efficiency of bituminous coal. Oil properly fired is a smokeless fuel and is largely used by the railroads adjacent to its source, but it is also limited in supply and the cost of its transportation would make it prohibitive for general use. Smoke-consuming

devices have so far been unsuccessful and the only thing of this kind in use today is the brick arch, which increases the course of the gases and delays their departure from the firebox, thereby assisting in their combustion.

I believe the real and only solution of the smoke problem is the education and supervision of the engineer and fireman. It is a joint problem between the two, for negligence on the part of one can defeat the good efforts of the other. This education on a big railroad is a great problem and involves the continuous efforts of a large number of officers. The railroads are at all times putting forth every energy and sparing no expense to reduce smoke to a minimum. As a result I believe I am safe in saying that great improvement has been made.

GEORGE H. BARRUS. The gases first evolved from a charge of coal thrown on a hand-fired furnace are in their original cold state. Contact with the hot atmosphere and radiant heat of the furnace increases the temperature of the exposed portions of the gases sufficiently to ignite them, and these take fire and burn away. Portions of gas which are not favorably exposed receive an insufficient quantity of heat to become thoroughly ignited, and these pass out of the furnace in an unconsumed state. It is the unheated gas thus formed which causes smoke, and the whole problem of smoke prevention lies in overheating, so to speak, these gases before leaving the combustion chamber, so that they will ignite. When these gases receive a proper amount of heat before reaching the boiler, they are burned without smoke, and the degree of smokelessness obtained depends on the degree with which the heating of the gases has been effected.

This feature of the subject may be illustrated by referring to an experiment I have made on a battery of two 300-h.p. vertical-pass horizontal water-tube boilers. The result aimed at was to ascertain the effect of firing the two boilers alternately and employing the incandescent coke of one furnace as a medium for overheating the gases evolved from fresh charges of coal in the other. An opening was cut through the intermediate wall between the two furnaces, extending horizontally the whole length of the grate and vertically to the lower row of tubes, putting the two furnaces into free communication. The closing of either of the flue dampers was sufficient to cause the products of combustion from the furnace of one boiler to pass through the intermediate opening and over the fuel bed of the other furnace, and thereby to secure the desired object. To make a comparison of the

smokelessness of this system with the ordinary system of operation the boilers were first run in their usual manner. The coal was New River and one boiler was fired at a time. The firing system employed consisted in charging the two outside doors first, there being three doors in all for each boiler, and then waiting a short time before charging the middle door.

Smoke observations were made every minute for a continuous period of two hours, the estimated percentage of black smoke being judged as it appeared to the eye when escaping from the top of the chimney. With the boilers operated in the ordinary manner, the average amount of smoke observed for the entire period of 2 hr., including the time when there was no smoke, was 13.6 per cent. The maximum amount was 75 per cent, and there was an entire absence of smoke, or only a trace of it, 54 min.

When the alternate system was brought into use, the three doors of each boiler were fired in rotation, there being no wait between doors. Smoke observations showed that the average amount of smoke during the entire period of 2 hr., including the time of no smoke, was 2.3 per cent. The maximum amount was 10 per cent, and there was an entire absence of smoke, or only a trace of it, 1 hr. 22 min. It will be observed that the latter method produced a marked effect upon the character of the smoke, reducing its density and the length of time it was visible. It may be added that by actual observation the smoky flame leaving the new coal was seen immediately to clear up on passing into the secondary furnace.

JOHN T. HAWKINS. There can be very little doubt that the suppression of smoke is a desideratum and a great one, if it is for physical reasons only; but there has been, I think, a great deal of exaggeration as to the economy of smokeless combustion. In the products of combustion from bituminous coal there are not only losses from fixed carbon, the real smoke, but from uncombined carbon in the form of CO. As far back as 1874 or 1875 there was great furor in and around New York, about reducing the smoke from soft coal, and many extravagant claims were made as to the losses in burning bituminous coal. Theron Steel, a graduate of the first class of engineers from the Naval Academy, and myself conducted in 1874 to 1875 in New York a series of experiments to determine what was the difference in economy between the heaviest, smokiest firing that could be made and absolutely clear, smokeless firing with bituminous coal. The apparatus was especially prepared and set up in such a way that

perfectly transparent white-hot gases could be made to pass out of the combustion chamber and the boiler tubes with no sign of smoke issuing from the chimney at any time. We could also fire for an extreme amount of smoke. There were peep-holes arranged to permit the examination of the character of the combustion and of the escaping gases. All kinds of coal were used, and the analyses were exhaustive in every way. The results were that we found that between the most smoky fire we could make by hand-shovel firing, and the clear smokeless fire, there was never more than a loss of about 0.7 of 1 per cent, more than half of which was due to the increased escape of CO, which always obtained with smoky firing. The greatest actual loss of fixed carbon was, therefore, only about 0.3 of 1 per cent, which shows that the economy feature of the smoke problem is of little importance.

If this loss were as great as Mr. Randall quotes in his paper (3 to 6 per cent) attempts would have been made long before 1874 or 1875 to do away with bituminous smoke, and the question would today be a much more agitated one than it really is.

CHAS. H. BIGELOW. In looking over some old drawings dating as far back as 1785, we find that smoke abatement is not a new problem, but one that inventors have been working on ever since that time, and many and varied are the methods suggested for decreasing it.

James Watt in 1785 proposed hot funnels or pipes filling the space between the top of the bridge wall and the bottom of the boiler; J. & J. Roberton in 1800 introduced tubes in the front wall to admit cold air over the fire. In 1809 to 1812, perforated pipes located in the bridge wall and extending through the side walls were tried. A little later, methods of introducing air from the ash pit through the bridge wall and baffles back of the bridge wall were experimented with. In 1816, W. Losh proposed to divide the fire longitudinally and to pass the gases from one fire under the grate of the other. In 1838, D. Cheetham introduced a fan to draw the gases from the back of the bridge wall and to mix them with fresh air blowing them again through the fire. A deflecting arch over the fire was tried by R. Rodder in 1838. A coking plate in front of the furnace was designed by Howard and Sons, in 1840. J. Smethurst planned to draw the gases through a water chamber back of the bridge wall by means of an exhaust fan. J. Nutt placed a small secondary boiler back of the bridge wall to be heated by the gases, discharging the steam produced into the hot gases through a perforated pipe thus furnishing oxygen,

the gases being mixed by numerous baffle walls. In another method proposed by Johnson, a water tank divided into four sections is located back of the bridge wall and the gases deflected on the surface of each section by hanging walls. The water is thrown into the current of gases in the form of a spray by dash wheels, and is combined chemically with them. Many other methods were proposed from time to time including two grates in series and one above the other, also many different methods of introducing air into various parts of the combustion chamber and behind the bridge wall.

D. T. RANDALL. Nearly all these statements have been based on observations and experience with a particular apparatus and with fuels of the same general character. The various experiences in individual plants only emphasize the fact that burning bituminous coal efficiently without smoke is as important a problem as any which claim the attention of mechanical engineers.

It is possible to operate some plants smokelessly and at the same time inefficiently. Many plants are so designed that when operated to secure the highest economy, some smoke will be emitted from the stack and only a slight change in the conditions in the boiler room will cause them to smoke badly.

General conclusions regarding the smoke problem should not be based upon such plants alone. There has been considerable progress made in the design of furnaces during the past five years and there are many plants now operating in which bituminous coal is burned efficiently and without objectionable smoke.

GENERAL NOTES

AMERICAN SOCIETY OF CIVIL ENGINEERS

At the opening session of the 58th Annual Meeting of the American Society of Civil Enginers in the Society house at 220 West 57th Street, New York, January 18, 1911, annual reports were received and progress reports from the special committees on Steel Columns and Struts and on Bituminous Materials for Road Construction were presented for discussion. The following officers were elected for the year 1911–1912:

President, M. T. Endicott; Vice-Presidents, A. P. Boller, Mem.Am.Soc.M. E., C. L. Strobel; Treasurer, J. M. Knap; Directors, G. C. Clarke, H. G. Stott, Mem.Am.Soc.M.E., J. P. Snow, Robert Ridgway, L. W. Rundlett, W. H. Courtenay.

Two excursions occupied the afternoon, one to the plant of the Keuffel and Esser Company, Hoboken, N. J., where all kinds of scientific instruments used by engineers are manufactured; and the other to the Brooklyn Navy Yard. In the evening the President held a reception at the Society House, followed by informal dancing.

On Thursday the entire day was spent in a visit to the works of the Bethlehem Steel Company at Bethlehem, Pa., where inspection was made of the structural mill and the rolling of structural shapes; the rail mill and the rolling of open-heart steel rails; the ordinance works and the forging of guns and armor plate; the gun finishing machine shop where large guns and heavy machinery are under construction; two modern blast furnaces under construction; also the construction of a power plant for gas-driven electric power and gas power blowing engines. Luncheon was served at the works and the party was conveyed to and from Bethlehem by special train. An informal smoker on Thursday evening at the Society House completed the program of the convention.

Special meetings for topical discussion were held on Friday and Saturday, January 20 and 21, immediately following the convention, with Road Construction and Maintenance as the subject under consideration, and the following sub-divisions: Preliminary investigations, introduced by Logan W. Page; Relative Value of Three Methods of Carrying on Work, introduced by Harold Parker; Systems of Maintenance, introduced by Hubert K. Bishop; The Use of Water, Calcium Chloride, Light Oils, etc., as Dust Palliatives introduced by Samuel Whinery, Mem.Am.Soc.M.E., Surface Treatment with Tars, Heavy Oils, etc.,introduced by Charles W. Ross; The Use of Bituminous Materials by Penetration Methods, introduced by Walter W. Crosby; The Use of Bituminous Materials by Mixing Methods, introduced by Arthur H. Blanchard. A number of engineers especially interested in Road Construction were present and a very full discussion resulted.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

On Friday, January, 13, 1911, the subject of Corona was presented for consideration at the monthly meeting of the American Institute of Electrical Engineers, with two papers, one by Prof. Harris J. Ryan, Mem.Am.Soc.M.E., on Open Atmosphere and Dry Transformer Oil as High Voltage Insulators, and the other by E. L. West, on High Voltage Line Loss Tests made on 100-kilowatt, 60-cycle, 180-mile Transmission Line of the Central Colorado Power Company.

The Mid-Year Convention will be held in Pittsfield and Schenectady from February 14-16, 1911, and will be devoted to a consideration of the following papers: Mechanical Forces in Magnetic Fields, C. P. Steinmetz, Mem.Am.Soc. M.E.; Problems in the Operation of Transformers, F. C. Green; Protection of Electric Transmission Lines, E. F. C. Creighton; Tests of Grounded Phase Protector on the 44,000-Volt System of the Southern Power Company, C. I. Burkholder and R. H. Marvin; Tests of Losses of High Tension Lines, G. Faccioli; The Temperature Gradient in Oil-Immersed Transformers, James Murray Weed; Hysterises and Eddy Current Exponents for Silicon Steel, W. J. Wooldridge; Commercial Problems of Transformer Design, R. H. Wilson; Design, Construction and Test of an Artificial Transmission Line, J. H. Cunningham.

NEW ENGLAND WATER WORKS ASSOCIATION

The New England Water Works Association held its annual meeting on January 11, 1911, at the Hotel Brunswick, Boston, Mass. Reports were presented by the following committees: To look after and keep track of Legislation and other matters pertaining to the Conservation, Development and Utilization of the Natural Resources of the Country, M. N. Baker, Chairman, New York City; to prepare a Standard Specification for Fire Hydrants, H. O. Lacount, Mem.Am.Soc.M.E., Chairman, Boston; On Information as to the Conditions under which Extensions of Water Mains are made by Town Owned Water Supplies, Charles W. Sherman, Chairman, Boston; On Uniformity of Hose and Gatenuts and Direction of Opening, Frank L. Fuller, Chairman, Boston; To Compile Information relating to Awards that have been made in Water Works Valuation Cases, H. W. Dean, Chairman, Boston; On Library, Charles W. Sherman, Chairman, Boston. An address was made by the retiring President George A. King, of Taunton, Mass., and reports received from other officers of the association. The following officers were elected for the ensuing year: President, Allen Hazen, New York; Vice-Presidents, J. Waldo Smith, Mem.Am.Soc. M.E., New York, Michael F. Collins, Lawrence, Mass., Leonard Metcalf, Mem.Am.Soc.M.E., Boston, Mass., Irving S. Wood, Providence, R. I., Frank A. McInnes, Boston, Mass., Morris Knowles, Mem. Am. Soc. M. E., Pittsburg; Secretary, Willard Kent, Narragansett Pier, R. I.; Treasurer, Lewis M. Bancroft, Reading, Mass., Editor, Richard K. Hale, Boston, Mass.

COURSE ON POWER AND PROPULSION AT POLYTECHNIC INSTITUTE

A course of lectures on the subject of Power and Propulsion will be given at the Brooklyn Polytechnic Institute by Prof. W. D. Ennis, Mem.Am.Soc.M.E.,

commencing February 1, and continuing through fourteen succeeding Wednesdays, at 6.30 p.m. The course is designed to show the physical principles underlying the determination of resistances to motion in the steam locomotive, the automobile, the aeroplane and the dirigible balloon, and to develop the leading factors involved in computation of power equipment.

BROOKLYN ENGINEERS CLUB

At a meeting of the Brooklyn Engineers Club, held at the Club House, Thursday evening, January 12, Henry P. Rust presented a paper upon the Hydro-Electric Power Plant of the Great Western Power Company, of San Francisco, Cal., on the North Fork of Feather River. This was illustrated by lantern slides. The location and characteristics of the river, the watershed and its possibilities, and the design and construction of the 55,000-h.p. hydro-electric plant at Big Bend were particularly dealt with.

Informal library talks were given on January 19, on the Lubrication of Cylinders, by R. C. Garhart; and on January 26 on the Reconstruction and Standardization of the Rolling Stock of the Brooklyn Rapid Transit Company, by W. G. Gove.

WISCONSIN ELECTRICAL ASSOCIATION

The annual convention of the Wisconsin Electrical Association was held on January 18 and 19 at the Hotel Pfister in Milwaukee, with papers and discussions on Publicity Campaigns, Some Principles established by the Wisconsin Railroad Commission; Electric Meter Testing; Ornamental Street Lighting; Insurance; Electric Railway Repair Shop Practice. Various social features added to the enjoyment of the meetings.

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

The American Society of Heating and Ventilating Engineers held its 17th annual meeting in the Engineering Societies Building, New York, on January 24-26, 1911. At the business meeting held at its opening session on Tuesday afternoon, the following officers were elected: President, R. P. Bolton, Mem. Am.Soc.M.E.; 1st Vice-Presidents, John R. Allen, Mem.Am.Soc.M.E., S.R. Lewis; 2d Vice-Presidents, A. B.Franklin, Ralph Collamore; Secretary, Wm. M. Mackay; Treasurer, U. S. Scollay. On Wednesday evening the annual dinner was held at the New Grand Hotel. At the professional sessions, occupying both Wednesday and Thursday pretty fully, papers were read and discussed, including the Value of Good Ventilation, by Prof. Severance Burrage, of Purdue University; Standards of Ventilation, by Dr. W. A. Evans, of Chicago; Ventilation of the Capitol, Washington, D. C., by Nelson S. Thompson; Pipe Line Design for Central Station Heating, by B. T. Gifford, Mem.Am.Soc.M.E., Chicago. Topical discussions were also conducted upon Objections to the Making of Plans by Manufacturers for the Installation of their Apparatus; Use of Vacuum Systems in Heating Buildings; Smokeless Combustion in Steam Heating Plants; Reliable Data for Estimating the Radiation for Buildings of All

Classes; Value of Exhaust Steam as Compared with Live Steam for Heating Purposes; Desirability of having Ventilating Laws applied to Private Schools as well as Public Schools.

THE NATIONAL CIVIC FEDERATION

Delegates from all parts of the country, representing nearly every branch of industry, attended the eleventh annual meeting of The National Civic Federation, held in the Hotel Astor on January 12–14, 1911. President Seth Low of the Federation made his annual address and report upon the year's work at the opening session, and this was followed by a discussion upon the Regulation of Combinations and Trusts from the State and Federal standpoint. At the afternoon session Industrial Efficiency was presented including consideration of the piecework, bonus and premium systems of payment for labor. Among the speakers were Harrington Emerson, Mem.Am.Soc.M.E.; H. L. Gantt, Mem.Am.Soc. M.E.; Warren S. Stone; James O'Connell. The Need for Uniform State Legislation was presented in a symposium on Friday morning, on the subjects of Taxation, Banking, Insurance, Pure Food and Drugs, Reform in Legal Procedure, Regulation of Railways, Good Roads Building, Regulation of Corporations, and the Commercial Bills of the Uniform State Law Commissioners. Friday afternoon was devoted to a consideration of the Workmen's Compensation Act proposed by the Department of Compensation for Industrial Accidents and their Prevention, August Belmont, Chairman. This bill has been drawn up as the result of a year's careful work by the Legal Sub-Committee, P. Tecumseh Sherman, Chairman. In addition to members of the department, Col. Theodore Roosevelt, Andrew Carnegie, Hon. Mem.Am.Soc.M.E., John Mitchell and James Duncan, made addresses heartily advocating the bill.

The annual dinner of the Federation was given at the Hotel Astor on Friday evening, President Seth Low acting as toastmaster. Mediation and Arbitration of Industrial Disputes was discussed on Saturday morning.

SOCIETY OF AUTOMOBILE ENGINEERS

The Society of Automobile Engineers, which has within the last few months doubled its membership, held a largely attended annual meeting on January 11 and 12, 1911 in the assembly hall of the Automobile Club of America, New York City. At the business meeting on the first day of the convention, the following officers were elected: President, Henry Souther, Mem.Am.Soc.M.E.; Managers, Henry May, Howard Marmon, C.E. Davis, Mem.Am.Soc.M.E. Wednesday evening was occupied by a dinner and entertainment, with addresses by the retiring president, H. E. Coffin, Mem.Am.Soc.M.E., and the president-elect.

Four professional sessions were held, one Wednesday afternoon and the others on Thursday morning, afternoon and evening. A large number of papers were presented, including Electro Steel, by Joseph Schaeffers; Illustrations of Physical Facts relating to Metallurgy, by Radclyffe Furness; Construction of Highways for Motor Traffic, by Logan Waller Page; Leaf Springs, by E. K. Rowland; Novelties in Valve Systems, by E. P. Batzell; Hot Rolled Gears, by H. N. Sanderson; Commercial Gasoline and the Impurities that are being encountered, by F. H. Floyd; Test of a 20-h.p. Franklin Air-Cooled Motor, Prof. R. C.

Carpenter, Mem.Am.Soc.M.E.; Development of the Grinding Wheel, by Geo. N. Jeppson; Methods of Grinding, John C. Spence; Frictionless Friction Drive, Charles E. Duryea; Fire Protection Question, N. B. Pope; Automobile Contest Timing and Coaching, by Chester S. Ricker; Advantages of Long-Stroke Motors, E. A. Myers; Coöperation between the Electric Vehicle Manufacturer and the Central Station, Robert McA. Lloyd; The Ampere-Hour Meter for Electric Vehicles, by R. C. Lanphier; Gasoline-Electric Transmissions for Heavy Loads, by Alex. Churchward.

Reports of Committees on Standards were received: Iron and Steel Division, M. T. Lothrop, Mem.Am.Soc.M.E., Aluminum and Copper Alloys Division, Wm. H. Barr; Ball and Roller Bearings Division, D.F.Graham; Broaches Division, C. E. Davis, Mem.Am.Soc.M.E.; Carbureter Division, G. G. Behn; Gear Metals Constants Division, G. W. Sargent; Frame Sections Division, James H. Foster; Lock Washers Division, Frederick S. Sayre; Nomenclature Division, A. L. McMurtry; Seamless Steel Tubes Division, H. W. Alden, Mem.Am.Soc.M.E.; Sheet Metals Division, H. E. Coffin, Mem.Am.Soc.M.E.; Springs Division, A. C. Bergmann; Tire Efficiency Division, F. J. Newman; Miscellaneous Division, Henry Souther, Mem.Am.Soc.M.E.

As the society was in session during the National Automobile Exhibit at Madison Square Garden, and the exhibit of the American Motor Car Manufacturers at Grand Central Palace, the time of the members was most fully and profitably occupied.

INVENTORS' GUILD

Dissatisfaction with existing relations between the inventor and the patent law has led to the organization of the Inventor's Guild, the object of which is stated in its constitution as follows: "The object of the Guild is to advance the application of the useful arts and sciences, to further the interests and secure full acknowledgment and protection for the rights of inventors, to foster social relations among those who have made notable advances in the application of the useful arts and sciences." The membership of the guild is to be limited and is to include not only men who have made inventions, but who have achieved some measure of success therewith, and who will therefore be capable of exerting some influence.

The officers are: Ralph D. Mershon, Mem.Am.Soc.M.E., president; Chas. W. Hunt, Mem.Am.Soc.M.E., 1st vice-president; Chas. S. Bradley, 2d vice-president; Thomas Robins, secretary, and Henry L. Doherty, Mem. Am. Soc. M. E., treasurer.

THE SIBLEY GRADUATE CLUB

With the recent installation in the Department of Experimental Engineering Sibley College, Cornell University, of an organized branch of research, with Prof. R. C. Carpenter, Mem.Am.Soc.M.E., at the head, a new stimulus has been given to experimental research work. This has been still further augmented by the formation of a Sibley Graduate Club, composed of all advanced and graduate students taking work in Sibley College, to promote and encourage original investigation among the graduate students.

The officers of the club are: President, T .C. Ulbricht, Jun.Am.Soc.M.E.; Vice-President, A. G. Bierma; Secretary and Treasurer, C. A. Carpenter.

PERSONALS

C. E. Ard, formerly located at Starkville, Miss., has been appointed professor of mechanical engineering of the Mississippi Agricultural and Mechanical College, Agricultural College, Miss.

Frank G. Bolles has become identified with the Reliance Engineering & Equipment Co., Milwaukee, Wis. Until recently he was in the employ of the Allis-Chalmers Co., of the same city.

W. Van Alan Clark, recently associated with the Astoria Light, Heat & Power Co., Astoria, L. I., N. Y., has become affiliated with the Consolidated Gas Co., as assistant superintendent of the 99th St. Works, New York.

T. B. Davis has severed his connection as chief engineer of the Cleveland Crane & Engineering Co., Wickliffe, O., to accept the position of president and general manager of the Arkansas Farms Co., Little Rock, Ark.

Wm. J. Edwards has become connected with the Binghamton Clothing Co., Binghamton, N. Y., in the capacity of vice-president and treasurer. Mr. Edwards was formerly in the employ of the Tide Water Oil Co.

Harry Gay, formerly associated with A. L. Drum & Co., Chicago, Ill., has become connected with the Stone & Webster Engineering Corp., Boston, Mass.

W. E. Gray has sold his interests in the Skaneateles Paper Co., Skaneateles, N. Y., and is now general sales manager of The Enameled Pipe & Engineering Co., Elyria, O.

Charles A. Francis has become identified with the National Printing Machinery Co., Inc., Athol, Mass., as manufacturing superintendent.

George Hanson, formerly superintendent of the Charter Gas Engine Co., Sterling, Ill., has become president and general manager of the Havana Manufacturing Co., Havana, Ill.

W. E. Lindsay, consulting engineer, formerly located at Birmingham, Ala., has assumed the position of secretary and treasurer of the American Welding Co., Carbondale, Pa.

W. L'E. Mahon has become associated with the Titan Steel Casting Co., Newark, N. J. He was recently identified with the Taylor Iron & Steel Co., New York.

R. S. de Mitkiewicz, lately associated with the Alden Sampson Manufacturing Co., has become affiliated with the Motors Engineering & Sales Co., of New York, in the capacity of power sales engineer.

John I. Rogers, formerly associated with the Midvale Steel Co., Philadelphia, Pa., has opened a New York office for the practice of consultation and design.

William H. Smead, formerly employed as engineer with the General Fire Extinguisher Co., has been promoted to engineer of the Western heating and power piping department of the same company, with headquarters at Warren, O.

C. N. Thorn has resigned the position of assistant manager of the machinery department of Manning, Maxwell & Moore, Inc., New York, to accept the position of purchasing agent and mechanical engineer with Hugh, Kelly & Co., New York.

Wm. B. Updegraff has entered the employ of the Architectural Tile & Faience Co., Maurer, N. J. He was formerly associated with the Harlem Contracting Co., New York.

Thos. J. Walsh, who has been connected with the Stone & Webster Engineering Corp., Boston, Mass., as engineer, has opened an office in Boston, Mass., with the examining, estimating and designing for electric and manufacturing plants as his specialty.

ACCESSIONS TO THE LIBRARY

This list includes only accessions to the library of this Society, included in the Engineering Library. Lists of accessions to the libraries of the A. I. E. E. and A. I. M. E. can be secured on request from Calvin W. Rice, Secretary, Am. Soc. M. E.

AMERICAN RAILWAY ASSOCIATION. Proceedings. St. Louis, November 1910. Gift of Association.

BRITISH ASSOCIATION OF GAS MANAGERS. Proceedings. 1880, 1881. *London, 1880, 1881.*

CONSTRUCTION AND WORKING OF INTERNAL COMBUSTION ENGINES. By R. E. Mathot. Translated from the French by W. A. Tookey. *New York, D. Van Nostrand Co., 1910.* Gift of author.

ELECTRICAL ENGINEERS' POCKET BOOK, 1911. Eleventh annual edition. Edited by W. H. Fowler. *Manchester, Scientific Pub. Co.* Gift of publishers.

ELEMENTS OF GRAPHIC STATICS AND OF GENERAL GRAPHIC METHODS. By W. L. Cathcart and J. I. Chaffee. *New York, D. Van Nostrand Co., 1910.* Gift of publishers.

FALL RIVER RESERVOIR COMMISSION. Report upon Improvement of the Quequechan River, 1910. *Lowell, 1910.* Gift of Arthur T. Safford.

GAS INSTITUTE. Transactions. 1882, 1883, 1886–1890. *London, 1882–1890.*

HOISTING AND CONVEYING MACHINERY. Compiled by Paul Stülpnagel. Deinhardt-Schlomann Series of Technical Dictionaries in Six Languages, vol. 7. *London, Constable & Co., Ltd., 1910.*

INDIA RUBBER AND ITS MANUFACTURE. By H. L. Terry. *New York, D. Van Nostrand Co., 1907.*

INFLUENCE OF MECHANICAL DRAFT UPON THE ULTIMATE EFFICIENCY OF STEAM BOILERS. By W. B. Snow. Reprinted from the Columbia Engineer, Columbia University. Gift of B. F. Sturtevant Co.

INTERNAL COMBUSTION ENGINE. By H. E. Wimperis. *New York, D. Van Nostrand Co., 1908.*

IRON AND STEEL. A pocket encyclopedia, including Allied Industries and Sciences. By H. P. Tiemann. With an introduction by H. M. Howe. *New York, McGraw-Hill Book Co., 1910.* Gift of publishers.

LELAND STANFORD JUNIOR UNIVERSITY. Alumni Directory and Ten-Year Book, vol. 2, 1891–1910. *Stanford University, 1910.*

LONG DISTANCE TRANSMISSION OF STEAM AND ITS EFFECT ON POWER PLANT ECONOMICS. Univ. of Wisconsin Engineering Service Bulletin, vol. 6. no. 3. By H. J. Thorkelson. *Madison, 1910.* Gift of C. W. Rice.

MECHANICAL DRAFT. A Practical Treatise. Edited by W. B. Snow. *Boston, B. F. Sturtevant Co.* Gift of B. F. Sturtevant Co.

MECHANICAL ENGINEERS' POCKET BOOK, 1911. Thirteenth annual edition. Edited by W. H. Fowler. *Manchester, Scientific Pub. Co.* Gift of publisher.

MECHANICAL VENTILATION AND HEATING BY A FORCED CIRCULATION OF WARM AIR. By W. B. Snow. *Boston, B. F. Sturtevant Co.* Gift of B. F. Sturtevant Co.

MECHANICS' AND MACHINISTS' POCKET BOOK AND DIARY, 1911. Edited by W. H. Fowler. *Manchester, Scientific Pub. Co.* Gift of publishers.

NEW YORK CITY BOARD OF ESTIMATE AND APPORTIONMENT. Communication from F. J. Sprague. Gift of C. W. Rice.

NEW YORK STATE LIBRARY. 24th Annual Report of the New York State Library School, 1910. *Albany, 1910.*

PAPER TECHNOLOGY. An Elementary Manual. ed. 2. By R. W. Sindall. *London, Chas. Griffin & Co., 1910.*

PENNSYLVANIA STATE COLLEGE, SCHOOL OF ENGINEERING. Announcement, 1910–1911. *State College, 1910.* Gift of the college.

PHYSICAL SIGNIFICANCE OF ENTROPY OR OF THE SECOND LAW. By J. F. Klein. *New York, D. Van Nostrand Co., 1910.* Gift of author.

REINFORCED CONCRETE IN SUB- AND SUPERSTRUCTURE. Compiled by Heinrich Becher. Deinhardt-Schlomann Series of Technical Dictionaries in Six Languages, vol. 8. *London, Constable & Co., Ltd., 1910.*

TRAVELING ENGINEERS' ASSOCIATION. Proceedings of the 18th Annual Convention, 1910. *Buffalo, 1910.*

U. S. LIGHT HOUSE BOARD. Annual Report of the Operations. 1910. *Washington, 1910.* Gift of Light House Board.

VENTILATION IN ITS RELATION TO HEALTH. By W. G. Snow. Gift of Warren Webster & Co.

WEBB'S ACADEMY AND HOME FOR SHIPBUILDERS. Annual Report, 1910. *New York, 1910.* Gift of the Academy.

GIFT OF MRS. F. B. HALL

APPLIED MECHANICS. By G. Lanza. *New York, 1886.*

ARCHITECTS AND BUILDERS' POCKETBOOK. By F. E. Kidder. ed. 13. *New York, 1902.*

BUILDING ESTIMATOR. By Wm. Arthur. *1904.*

BUILDING SUPERINTENDENCE. By T. M. Clark. ed. 8. *Boston, 1890.*

CARNEGIE STEEL COMPANY. Pocket Companion, 1903. *Pittsburg, 1903.*

CRANE COMPANY COMPLETE POCKET CATALOGUE, STEAM GOODS, ETC. August 1902. *Chicago, 1902.*

ELECTRICAL CATECHISM. By A. J. DuBois. *New York, 1902.*

ELEMENTS OF THE DIFFERENTIAL AND INTEGRAL CALCULUS, WITH EXAMPLES AND APPLICATIONS. By J. M. Taylor. *Boston, 1886.*

ELEMENTS OF MACHINE DESIGN. By W. C. Unwin. ed. 10. *London, 1888.*

GAS ENGINE. By Dugald Clerk. ed. 2. *New York, 1887.*

HYDRAULICS AND HYDRAULIC MOTORS. By A. J. DuBois. *New York, 1889.*

INDICATOR PRACTICE AND STEAM ENGINE ECONOMY. By F. F. Hemenway. ed. 2. *New York, 1888.*

INTERNATIONAL CORRESPONDENCE SCHOOL. Electrical Engineers' Pocketbook. *Scranton, 1908.*

——MECHANICS' POCKET MEMORANDA. ed. 6. *Scranton, 1903.*

——TELEPHONE AND TELEGRAPH ENGINEERS' POCKETBOOK. *Scranton, 1908.*

MANUAL OF MECHANICS OF ENGINEERING. By P. J. Weisbach. *New York, 1889.*

NATIONAL TUBE COMPANY. Book of standards and useful information containing tables of sizes and other useful information pertaining to tubular goods. *Pittsburgh, 1902.*

PRACTICAL TEXT BOOK ON PLANE AND SPHERICAL TRIGONOMETRY. By Webster Wells. *Boston, 1883.*

STRAINS OF FRAMED STRUCTURES. By A. J. DuBois. ed. 9. *New York, 1892.*

TABLES OF THE PROPERTIES OF SATURATED STEAM AND OTHER VAPORS. By C. H. Peabody. *New York, 1888.*

THEORY OF STRUCTURES AND STRENGTH OF MATERIALS. By H. T. Bovey. ed. 3. *New York, 1900.*

THERMODYNAMICS OF THE STEAM ENGINE AND OTHER HEAT ENGINES. By C. H. Peabody. *New York, 1889.*

TREATISE ON ELEMENTARY GEOMETRY. By Wm. Chauvenet. *Philadelphia, 1885.*

TREATISE ON MASONRY CONSTRUCTION. By I. O. Baker. ed. 3. *New York, 1890.*

EXCHANGES

AMERICAN RAILWAY MASTER MECHANICS' ASSOCIATION. Report of the Proceedings of the 43d Annual Convention. 1910. *Chicago, 1910.*

ECOLE D'APPLICATION DU GÉNIE MARITIME. Cours d'Electricité. *1907–1908.*

INSTITUTION OF MECHANICAL ENGINEERS. Brief Subject Index of Papers Published in the Proceedings. *1847–July 1910.*

LIVERPOOL ENGINEERING SOCIETY. Transactions. vol. 31. *Liverpool, 1910.*

U. S. NAVAL OBSERVATORY. Synopsis of the Report of the Superintendent of the United States Naval Observatory. 1910. *Washington, 1910.*

UNIVERSITY OF ILLINOIS ENGINEERING EXPERIMENT STATION BULLETIN. vol. 4–5. *Urbana, 1909, 1910.*

EMPLOYMENT BULLETIN

The Society has always considered it a special obligation and pleasant duty to be the medium of securing better positions for its members. The Secretary gives this his personal attention and is most anxious to receive requests both for positions and for men available. Notices are not repeated except upon special request. Copy for notices in this Bulletin should be received before the 12th of the month. The list of men available is made up of members of the Society and these are on file, with the names of other good men not members of the Society, who are capable of filling responsible positions. Information will be sent upon application.

POSITIONS AVAILABLE

060 Assistant engineer for water works plant. Technical graduate preferred, good knowledge of steam engineering and operation of boiler plants. Location Indiana.

061 Designer of heavy duty marine engines. Well established marine engineering department building engines for pleasure purposes. Man desired should be able to guide not only along mechanical lines in respect to the heavy duty engines, but be safe man from commercial standpoint. Location Michigan.

062 Assistant to manufacturing superintendent. Concern employing 1200 to 1400 men on varied lines. Loyal, energetic and tactful manufacturing man. Location Michigan.

063 Large manufacturing company in Philadelphia, first-class salesman familiar with commercial and mechanical end of selling electric trucks. State age, experience, and references, also salary expected.

064 Steam engineer, power house and sub-station work of large railway. Salary between $200 and $250 per month. Location New York.

065 Chief engineer; power department Cement Company totalling about 4000 h. p., 75 per cent gas engine operating on natural gas. Will pay $2000 a vear salary to start. Location Kansas.

066 Man to work through factory improving manufacturing methods and factory organization. Would prefer one who has spent year or two in shops in direct contact with manufacturing or cost keeping. Pay at the start $1000. Location Canada.

067 Man to take charge of the manufacturing of small Canadian factory, with executive as well as manufacturing experience. Pay at the start $1200 to $1500. Manufacture of all kinds of spoons, forks, knives, pitchers, etc.

068 Engineer having knowledge of process of manufacturing carborundum. competent to superintend the construction and operation of plant. Salary commensurate with responsibilities of position. Location Rhode Island.

069 Assistant superintendent, good organizer, must know how to handle men properly and be able to produce work of the best quality at lowest cost. Prefer man thoroughly acquainted with cotton mill machinery and what machinery has to do in the mills. Location Massachusetts.

070 Engineer on design, estimating and sale of punching and shearing machinery, air compressors, etc. Location Michigan.

MEN AVAILABLE

161 Member, experienced in hydro and steam electric plant design and operation, desires position as designing engineer or superintendent. Thorough technical education; twelve years experience. At present employed. Best of references.

162 Junior, twenty-six. Graduate Mass. Inst. Tech., three years in Far East as manager for machinery importing house; desires position in sales department of large manufacturing concern, especially familiar with machine tool lines; had unlimited responsibility in executive position.

163 Stevens graduate, long experience in design, construction and management of manufacturing plants, patents, cost system, purchasing; specially interested in economics, organization and reduction of costs, from boiler room to finished product. Desires position in executive capacity, with new business or one needing reorganizing; would invest in the undertaking.

164 Engineer, works manager, designer and salesman, broad acquaintance in New York City and elsewhere, would like to form partnership with two congenial men or established firm of engineers. Can take leading part in business getting or in practical engineering work, in systematizing and management for results. Can work in accordance with system or principles of head of firm or independently.

165 Member, graduate in mechanical engineering; twelve years experience, seven years with Eastern institution, design and supervision of lighting, heating, ventilating and power plant installations; desires position with consulting engineer or architect. Salary $2400.

166 Junior member, married, technical graduate in mechanical engineering and manual training, four years experience in special work of large industrial plant. Experience would be of benefit in almost any line.

167 Technical graduate desires position as chief draftsman or engineer, experience in steam engineering, gas producer design and operation, fuel and gas analysis. Location New York or vicinity.

168 Graduate mechanical and metallurgical engineer, desires connection as consulting or chief engineer with company engaged in extensive development, exploitation and operation of mining properties or metallurgical processes. Wide experience in United States, Canada, Mexico and Europe. Especially qualified to determine or develop methods for ore treatment with particular regard for economic features. Design complete reduction works, power accessories and transportation facilities and supervise construction and management of same.

169 Electrical and mechanical engineer, eighteen years varied experience in electrical construction, steam and electrical power plant equipment, operation and repairs, ice-making and refrigerating engineering and construction. Good organizer and executive; desires position as general manager or chief engineer.

170 Member, desires position as general superintendent, representative, or consulting engineer in Boston or other New England manufacturing concern, devoting all or part of time.

171 Stevens Institute M.E., 1900, past ten years associated with large electrical manufacturing concern, extensive experience in factory management embracing cost reduction, production, etc., cost systems and selling. Engaged at present but wishes to locate in New York city or vicinity as works or office manager.

CHANGES IN MEMBERSHIP

CHANGES OF ADDRESS

ARD, Charles Edgar (1908), Prof. Mech. Engrg., Miss. A. & M. College, Agricultural College, Miss.

AUTENRIETH, George C. (Junior, 1908), Instr., Descriptive Geometry and Drawing, College of the City of N.Y., New York, N. Y., and *for mail*, 55 Second St., Weehawken, N. J.

BAKER, Chalice Whitmore (1905), Mech. Engr., Allis-Chalmers Co., and *for mail*, 273 Howell Ave., Milwaukee, Wis.

BEECHER, J. F. (Associate, 1908), Checker, Indiana Steel Co., and *for mail*, 660 Adams St., Gary, Ind.

BENNETT, Geo. G. (Junior, 1903), Engrg. Dept., Am. Thread Co., 549 Main St., and *for mail*, 433 Elm St., Holyoke, Mass.

BIRKINBINE, John (1888), Cons. Engr., Parkway Bldg., Broad and Cherry Sts., Philadelphia, and *for mail*, Cynwyd, Montgomery Co., Pa.

BLAKESLEE, Frank Arthur (1910), Mech. Supt., Taquah Min. & Exploration Co., Tarkwa, Gold Coast Colony, West Africa, and 1233 Prospect Ave., Kansas City, Mo.

BOLLES, Frank G. (Associate, 1901), Reliance Engrg. & Equip. Co., Engrg. Bldg., Milwaukee, Wis.

BUCK, Irwin (Junior, 1907), Mgr., Alcohol Utilities Co., 156 W. 23d St., and *for mail*, 342 W. 56th St., New York, N. Y.

CARPENTER, Alfonso H. (Associate, 1895), Westlake Hotel, 720 Westlake Ave., Los Angeles, Cal.

CHAMBERS, Norman C. (Junior, 1905), Export Dept., Niles-Bement-Pond Co., 111 Broadway, New York, N. Y.

CLARK, W. Van Alan (Junior, 1910), Asst. Supt., 99th St. Wks., Consltd. Gas Co., 99th St. and 2d Ave., New York, N. Y.

CLERGUE, Bertrand J. (Associate, 1907), Cons. Engr., Rm. 711, 90 West St., New York, N. Y.

COWARD, Herbert (Junior, 1905), Coward & Long, Peoples Bank Bldg., Wilkes-Barre, and 28 Philadelphia Ave., West Pittston, Pa.

DAVIS, Thomas B. (1907; 1909), Pres. and Genl. Mgr., Arkansas Farms Co., 804 State Bank Bldg., Little Rock, Ark.

DICKINSON, William Noble (1906), Mgr., Foreign Dept., Otis Elev. Co., 17 Battery Pl., New York, and 38 De Koven Court, Brooklyn, N. Y.

DIRKS, Henry B. (Junior, 1907), 3811 N. Seeley Ave., Chicago, Ill.

ELLENBOGEN, Sidney Arthur (Junior, 1910), Manhattan Shirt Co., 207 River St., and *for mail*, 635 Broadway, Paterson, N. J.

ELLIOTT, Elmer G. (1907), J. G. White & Co., Inc., Engrs., Contrs., Alaska Commer. Bldg., San Francisco, and *for mail*, 1063 Oak St., Oakland, Cal.

EVANS, William Francis (1897), Mech. and Production Engr., Deere & Co., and *for mail*, 2001 Seventh Ave., Moline, Ill.

FRANCIS, Charles A. (Associate, 1906), Mfg. Supt., Natl. Ptg. Mchy. Co., Inc., 167 Hapgood St., and *for mail*, P. O. Box 979, Athol, Mass.

GAY, Harry (Associate, 1907), Stone & Webster Engrg. Corp., 147 Milk St., Boston, Mass.

HOLMAN, R. Claude (1907), Ch. Engr., Hooven-Owens-Rentschler Co., Hamilton, O.

JOHNSON, Bradley S. (Associate, 1909), Rep., The T. H. Symington Co., Maryland Trust Bldg., and *for mail*, 2938 Clifton Ave., Baltimore, Md.

LAWRENCE, Howard F. (Junior, 1908), Am. Ship Windlass Co., and *for mail*, 111 Abbott St., Providence, R. I.

LELAND, William Emmons (1904), Cons. Engr., 832 Merchants Exch., San Francisco, and Berkeley, Cal.

LINDSAY, W. Edward (1895), Secy. and Treas., Am. Welding Co., and 31 Garfield Ave., Carbondale, Pa.

LONGWELL, Henry E. (1901), Cons. Engr., Westinghouse Mch. Co., East Pittsburg, and 206 N. Homewood Ave., Pittsburg, Pa.

McJILTON, John Perkins (Junior, 1910), Draftsman, Superheater Dept., Am. Loco. Co., and *for mail*, Box 384, Schenectady, N. Y.

McMULLIN, Frank V. (1903), 5805 Master St., Philadelphia, Pa.

MAHON, Wm. L'E. (1889), Titan Steel Casting Co., Newark, N. J., and 610 Church St., Ann Arbor, Mich.

MANTON, Arthur Woodroffe (1908), Civ. and Mech. Engr., 10 Victoria St., Westminster, London, and Ellerburn, Woodbourne Rd., Edgbaston, Birmingham, England.

MAYHEW, Ray (Associate, 1910), Asst. Ch. Draftsman, Mech. Dept., Minneapolis Steel & Mchy. Co., and *for mail*, 2800 17th Ave., S., Minneapolis, Minn.

MOON, Hartley Allen (Associate, 1908), in Charge of Drafting and Test Depts., Continental Gin Co., and 1703 14th Ave., S., Birmingham, Ala.

MURRIE, John L. (Junior, 1905), Ford, Bacon & Davis, 115 Broadway, New York, N. Y., and *for mail*, care Consltd. Gas Elec. Light & Power Co., Lexington and Liberty Sts., Baltimore, Md.

NICHOLL, John Seymour (Junior, 1909), 144 Columbia Hgts., Brooklyn, N. Y.

ORD, Henry C. (1905), Bath, Me.

POTTER, Wm. Bleecker (1895), Mgr. and Ch. Engr., St. Louis Sampling & Testing Wks., 713 Clark Ave., and 4021 Washington Blvd., St. Louis, Mo.

RANSOM, Allan (Associate, 1903), 237 Canyon Drive, Hollywood, Los Angeles, Cal.

RICHARDS, Francis H. (1880), Life Member; Mech. Engr., Pat. Atty., 9–15 Murray St., New York, N. Y., and *for mail*, 112 Edwards St., Hartford, Conn.

ROBINSON, Henry Smith (1896), Cons. Engr. and Pres., Atlantic Wks., 28 State St., Boston, and 97 Main St., Andover, Mass.

SHERMAN, C. K. (Associate, 1902), West. Rep., Under Feed Stoker Co. of Am., 714 Long Bldg., Kansas City, Mo.

SMITH, Geo. Marshall (Associate, 1904), V. P. and Treas., A. E. Anderson & Co., 28 Builders Exch., Buffalo, N. Y., and 4632 N. Winchester Ave., Chicago, Ill.

SOPER, Ellis (1905; Associate, 1908), Pres., The Soper Engrg. Co., 628 Ford Bldg., and 116 Gladstone Ave., Detroit, Mich.

TREGELLES, Henry (1888), Bartolmé Mitre 544, Buenos Aires, and Hurlingham F. C. Pacifico, Buenos Aires, Argentine Repub., S. A.

TURNER, Charles H. (Junior, 1905), P. O. Box 645, Worcester, Mass.

UPDEGRAFF, William Barrett (1910), Architectural Tile & Faience Co., Maurer, and 522 Magie St., Elizabeth, N. J.

WILSON, Jacob D. (Junior, 1903), Pres., Genl. Mgr. and Mech. Engr., Am. Elev. Co., 113-115 Cedar St., New York, N. Y., and *for mail*, 215 Essex Ave., Boonton, N. J.

YOUNG, E. R. (Junior, 1900), Biddle and West Sts., Wilkinsburg, Pa.

YOUNG, Gilbert A. (1906), Assoc. Prof. Engrg., Purdue Univ., and *for mail*, 409 Harrison St., West Lafayette, Ind.

NEW MEMBERS

BENTLEY, Oliver D. H. (1910), Turbine Dept., B. F. Sturtevant Co., Hyde Park, Mass.

CARDULLO, Forrest Ellwood (1910), Prof. Mech. Engrg., New Hampshire College, Durham, N. H.

MURRAY, Warren Edwards (1910), Ch. Engr., West. Sugar Refining Co., and *for mail*, 132 Grattan St., San Francisco, Cal.

NOTT, Albin James (Junior, 1910), Switchboardman in Charge Pumping Sta. No. 6, Sewerage and Water Bd., and *for mail*, 4122 Perrier St., New Orleans, La.

PROMOTIONS

TAFT, Theodore Howard (1903; 1910), Asst. Prof. Mech. Engrg., Mass. Inst. of Tech., Boston, and *for mail*, 1 Avon Pl., Cambridge, Mass.

VOSE, Fred Hale (1906; 1910), Asst. Prof. Mech. Engrg., Case Sch. of Applied Science, and *for mail*, 10,521 Lee Ave., N. E., Cleveland, O.

WHITTEMORE, Herbert L. (1903; 1910), Engr. of Tests, Watertown Arsenal, Watertown, Mass.

DEATHS

HENNING, Gustavus C., December 30, 1910.

PIERCE, Walter L., December 10, 1910.

GAS POWER SECTION

CHANGES OF ADDRESS

CORMACK, Geo., Jr., (Affiliate, 1908), Supt., Gas Eng. Dept., Independent Harvester Co., Plano, Ill.

DAVIDSON, T. C. (Affiliate, 1909), Erector, 429 27th Ave., Milwaukee, Wis.

KNOTT, Henderson W. (Affiliate, 1908), 114 Liberty St., New York, N. Y.

LATHROP, Jay Cowden (Affiliate, 1908), care Wm. Fargo, Jackson, Mich.

LUCKETT, Gustavus Tyler (Affiliate, 1908), Mgr., Piping Dept., M. W. Kellogg Co., 50 Church St., New York, N. Y.

McMULLIN, Frank V. (1908), Mem.Am.Soc.M.E.

DE MITKIEWICZ, R. S. (Affiliate, 1908), Power Sales Engr., Motors Engrg. & Sales Co., 250 W. 54th St., and *for mail*, 117 W. 58th St., New York, N. Y.

STUDENT BRANCHES

CHANGES OF ADDRESS

BAILEY, Raymond W. (Student, 1910), Phi Tau House, State College, Pa.
BESS, Earl (Student, 1910), Y.M.C.A., Denver, Colo.
HAYNES, H. Hasbrouck (Student, 1909), 84 Fulton St., New York, N. Y.
HEIBEL, Walter E. (Student, 1910), 414 Main Bldg., State College, Pa.
HERRMANN, George A. (Student, 1909), 6443 Jefferson Ave., Second Flat, Chicago, Ill.
LINLEY, Fred. H. (Student, 1910), 190 27th St., Milwaukee, Wis.
MINICH, Jay A. (Student, 1910), Delphi House, State College, Pa.
PAGE, Atwood C. (Student, 1909), present address unknown.
PARSONS, H. N. (Student, 1909), 41 W. 33d St., Chicago, Ill.
PERHAM, D. E. (Student, 1910), 312 Main Bldg., State College, Pa.
ROMIG, F. G. (Student, 1910), 636 Adams St., Gary, Ind.
SPERRY, F. E. (Student, 1909), 404 Kane St., Aurora, Ill.
STEED, Arthur (Student, 1910), 511 Jeannette St., Wilkinsburg, Pa.
WILLIAMS, Nezza N. (Student, 1910), 235 McAllister Hall, State College, Pa.

COMING MEETINGS

FEBRUARY—MARCH

Advance notices of annual and semi-annual meetings of engineering societies are regularly published under this heading and secretaries or members of societies whose meetings are of interest to engineers are invited to send such notices for publication. They should be in the editor's hands by the 15th of the month preceding the meeting. When the titles of papers read at monthly meetings are furnished they will also be published.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

February 10, monthly meeting, 29 W. 39th St., New York. February 14–16, Mid-Year Convention, Pittsfield, Mass., and Schenectady, N. Y. Papers: Mechanical Forces in Magnetic Fields, C. P. Steinmetz, Mem.Am. Soc.M.E.; Problems in the Operation of Transformers, F. C. Green; Protection of Electric Transmission Lines, E. F. C. Creighton; Test of Grounded Phase Protector on the 44,000-Volt System of the Southern Power Company, C. I. Burkholder and R. H. Marvin; Tests of Losses of High Tension Lines, G. Facciolo; The Temperature Gradient in Oil-Immersed Transformers, James Murray Weed; Hysterises and Eddy Current Exponents for Silicon Steel, W. J. Woodbridge; Commercial Problems of Transformer Design, R. H. Wilson; Design, Construction and Test of an Artificial Transmission Line, J. H. Cunningham. Secy., R. W. Pope, 29 W. 39th St., New York.

AMERICAN INSTITUTE OF MINING ENGINEERS

February 21, annual business meeting, 29 W. 39th St., New York, Secy., Dr. Joseph Struthers.

AMERICAN SOCIETY OF CIVIL ENGINEERS

February 1, 15, bi-monthly meetings, 220 W. 57th St., New York. Secy., C. W. Hunt.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

February 14, 29 W. 39th St., New York. February 17, Boston, Mass. Secy. Calvin W. Rice.

ASSOCIATION OF ONTARIO LAND SURVEYORS

February 28, annual meeting, Parliament Bldgs., Toronto, Canada. Secy., Killaly Gamble, 704 Temple Bldg.

BOSTON SOCIETY OF CIVIL ENGINEERS

February 15, Boston, Mass. Paper: Water Resources of the State of New York, Walter McCulloh. March 15, annual meeting, Boston City Club. Secy., S. Everett Tinkham, 715 Tremont Bldg.

CANADIAN MINING INSTITUTE

March 2–4, annual meeting, Quebec, Canada. Secy., H. Mortimer-Lamb. Rms. 3–4 Windsor Hotel, Montreal.

ENGINEERS' CLUB OF PHILADELPHIA

February 4, annual meeting, 1317 Spruce St. Secy., W. P. Taylor.

IOWA ENGINEERING SOCIETY

February 14, 15, 16, annual meeting, Des Moines. Secy., S. M. Woodward, Iowa City.

NATIONAL BRICK MANUFACTURERS' ASSOCIATION

February 6–11, annual convention, Louisville, Ky. Secy., T. A. Randall, Indianapolis, Ind.

NEBRASKA CEMENT USERS ASSOCIATION

February 1–3, annual convention, Omaha. Secy., Peter Palmer, Oakland.

NEW ENGLAND ASSOCIATION OF GAS ENGINEERS

February 15, annual meeting, Boston, Mass. Secy., N. W. Gifford, 26 Central Sq., East Boston.

NEW ENGLAND STREET RAILWAY CLUB

March 23, annual meeting, Boston, Mass. Secy., John J. Lane, 12 Pearl St.

NEW ENGLAND RAILROAD CLUB

February 14, New American House, Boston, Mass. Paper: Impressions of English Railway Service, W. J. Cunningham. Secy., Geo. H. Frazier, 10 Oliver St.

RAILWAY SIGNAL ASSOCIATION

March 20, Stated Meeting, Congress Hotel, Chicago, Ill. Paper: Alternating Current Signaling. Secy., C. C. Rosenberg, Bethlehem, Pa.

MEETINGS IN THE ENGINEERING SOCIETIES BUILDING

Date	Society	Secretary	Time
February			
1	Wireless Institute	S. L. Williams	8.00 p.m.
2	Blue Room Engineering Society	W. D. Sprague	8.15 p.m.
9	Illuminating Engineering Society	P. S. Millar	8.15 p.m.
10	American Institute Electrical Engineers	R. W. Pope	8.15 p.m.
14	American Society Mechanical Engineers	C. W. Rice	8.15 p.m.
17	New York Railroad Club	H. D. Vought	8.15 p.m.
21	New York Telephone Society	T. H. Lawrence	8.15 p.m.
22	Municipal Engineers of New York	C. D. Pollock	8.15 p.m.
March			
2	Blue Room Engineering Society	W. D. Sprague	8.15 p.m.
9	Illuminating Engineering Society	P. S. Millar	8.15 p.m.
10	American Institute Electrical Engineers	R. W. Pope	8.15 p.m.
17	New York Railroad Club	H. D. Vought	8.15 p.m.
21	New York Telephone Society	T. H. Lawrence	8.15 p.m.
22	Municipal Engineers of New York	C. D. Pollock	8.15 p.m.

CURRENT BOOKS

THE CONSTRUCTION AND WORKING OF INTERNAL COMBUSTION ENGINES. A Practical Treatise upon Methods of Construction, with Calculations for the Use of Engineers, Manufacturers, and Users, and a Critical Study of Present-day Types. By R. E. Mathot. *New York, D. Van Nostrand Co. 1910.* Cloth, 8vo, 554 pp., illustrated. Price, $5.

Contents: The Progress of Gas Power; Gas Versus Steam Engines; The Future of Gas Power; Principal Types of Gas Engines; Horizontal Gas Engines; Vertical Gas Engines; Marine Gas Engines; Two-Cycle Engines; Four-Cycle Engines; The Working of Gas Engines; Governing and Valve Gears; Details of Construction; Moving Parts; Testing and Testing Apparatus; Indicator Diagrams; Dimensions, Classifications, and Tests of Engines; Bibliography; Gas Engine and Gas Producer Makers; Device for Controlling Speed of Internal Conbustion Engines.

IRON AND STEEL. A Pocket Encyclopedia. Including Allied Industries and Sciences. By Hugh P. Tiemann. *New York, McGraw-Hill Book Co., 1910.* Leather, 12mo, 354 pp., illustrated. Price, $3.

PHYSICAL SIGNIFICANCE OF ENTROPY OR OF THE SECOND LAW. By J. F. Klein. *New York, D. Van Nostrand Co., 1910.* Cloth, 8vo, 98 pp. Price, $1.50 net.

Contents: Definitions, General Preliminary, Development, Current and Precise Statements of the Matters Considered; Analytical Expressions for a Few Primary Relations; The Physical Interpretations; Summary of the Connection between Probability, Irreversibility, Entropy, and the Second Law.

THE ELEMENTS OF GRAPHIC STATICS and of General Graphic Methods. By William Ledyard Cathcart and J. Irvin Chaffee. *New York, D. Van Nostrand Co. 1910.* Cloth, 8vo, 311 pp., 159 illustrations. Price, $3 net.

Contents: Graphic Arithmetic; Graphic Measurement of Areas; Forces: Concurrent, Non-concurrent, Non-parallel; Parallel Forces; Couples, Centre of Gravity; Moments; The Fundamental Theory of Beams; Framed Structures; Roof Trusses, Braced Cantilevers; Bridge Trusses; The Graphics of Friction; Moment Diagrams for Friction.

FOWLER'S ELECTRICAL ENGINEER'S POCKET BOOK, 1911. Edited by William H. Fowler. 11th annual edition. *Manchester, Scientific Pub. Co., 1911.* Cloth, pocket book size, 574 pp. Price, 1s., 6d.

Contents: Miscellaneous Tables, etc.; Wire Tables; Magnetism and Magnetic Data; Conductors and Insulating Materials; Electric Lighting and Wiring; Comparison and Measurement of Resistances; Electrical Measuring Instruments; Electricity Meters; Primary and Secondary Batteries; Dynamos and Motors; Alternate Electric Currents; Alternators; Transformers; Alternate Current Motors; Switchboards, Circuit Breakers, and Lightning Arresters; Electrical Power Transmission and Distribution; Rotary Converters; Electric Traction; Rules and Regulations.

FOWLER'S MECHANICAL ENGINEERS' POCKET BOOK, 1911. Edited by William H. Fowler. 13th annual edition. *Manchester, Scientific Pub. Co., 1911.* Cloth, pocket book size, 653 pp. Price, 1s., 6d.

Contents: Miscellaneous Tables and Formulae; Steam Boilers and Fittings; Fuels and Combustion; Steam Engines; Steam Turbines; Locomotives; Steam Tables; Valves and Valve Gear; Gas Engines; Gases used in Gas Engines; Oil Engines; Hydraulics; Pumps and Pumping Arrangements; Gearing and Lubrication; Hoisting and Lifting Machinery; Mining Machinery and Appliances; Metallurgy of Iron and Steel; Strength of Metals and Alloys; Beams and Pillars; Springs; Chemistry; Ventilation and Heating.

FOWLER'S MECHANICS' AND MACHINISTS' POCKET BOOK AND DIARY, 1911. Edited by William H. Fowler. *Manchester, Scientific Pub. Co., 1911.* Cloth, pocket book size, 456 pp. Price, 6d.

Contents: Handy References and Tables; Mensuration, Geometry and Trigonometry; Uses of Logarithms and Antilogarithms; Materials used in Machine Construction; Machine Tool Design; Proportions of Machine Tool Parts; Metal Cutting Tools; High Speed Tool Steels; Drilling and Boring Metal; Screw Threads, Screw Cutting and Taper Turning; Emery and Emery Wheels; Shop Practice; Wheel Gearing; Belt and Rope Driving; Shafting and Bearings; Lifting Ropes and Chains.

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PUBLICATION

H. F. J. Porter (1), *Chairman* — Geo. M. Basford (4)
Chas. I. Earll (5) — Geo. I. Rockwood (3)
Fred R. Low (2)

PUBLIC RELATIONS

James M. Dodge, *Chairman* — D. C. Jackson
Robert W. Hunt — J. W. Lieb, Jr.
Fred J. Miller

RESEARCH

W. F. M. Goss (3), *Chairman* — Jas. Christie (4)
R. C. Carpenter (5) — Ralph D. Mershon (2)
R. H. Rice (1)

Note.—Numbers in parentheses indicate number of years the member has yet to serve.

SPECIAL COMMITTEES
1911

On a Standard Tonnage Basis for Refrigeration

D. S. Jacobus — G. T. Voorhees
A. P. Trautwein — Philip De C. Ball
E. F. Miller

On Society History

John E. Sweet — Chas. Wallace Hunt — H. H. Suplee

On Constitution and By-Laws

Chas. Wallace Hunt, *Chairman* — F. R. Hutton
G. M. Basford — D. S. Jacobus
Jesse M. Smith

On Conservation of Natural Resources

Geo. F. Swain, *Chairman* — L. D. Burlingame
Charles Whiting Baker — M. L. Holman
Calvin W. Rice

On Identification of Power House Piping

H. G. Stott, *Chairman* — H. P. Norton
I. E. Moultrop — J. T. Whittlesey

On International Standards for Pipe Threads

E. M. Herr, *Chairman* — Geo. M. Bond
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On Standards for Involute Gears

Wilfred Lewis, *Chairman* — E. R. Fellows
Hugo Bilgrim — C. R. Gabriel
Gaetano Lanza

On Power Tests

D. S. Jacobus, *Chairman* — L. P. Breckenridge — Edward F. Miller
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On Standardization of Flanges

A. M. Mattice — J. P. Sparrow
Wm. Schwanhausser — H. G. Stott

On Student Branches

F. R. Hutton, Honorary Secretary

Tellers of Election

Wm. T. Donnelly — Geo. A. Orrok — Theo. Stebbins

MEETINGS OF THE SOCIETY

THE COMMITTEE ON MEETINGS

L. R. Pomeroy, *Chairman* (1) — Willis E. Hall (4)
C. J. H. Woodbury (5) — H. deB. Parsons (3)
Chas. E. Lucke (2)

Meetings of the Society in Boston

Ira N. Hollis, *Chairman* — I. E. Moultrop, *Secretary*
Edward F. Miller — James D. Andrew
Richard H. Rice

Meetings of the Society in New York

Walter Rautenstrauch, *Chairman* — Fredk. A. Waldron, *Secretary*
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Roy. V. Wright

Meetings of the Society in St. Louis

R. H. Tait, *Vice-Chairman* — Ernest L. Ohle, *Secretary*
M. L. Holman — Fred E. Bausch
John Hunter

Meetings of the Society in San Francisco

A. M. Hunt, *Chairman* — T. W. Ransom, *Secretary*
W. F. Durand — E. C. Jones
Thomas Morrin

Meetings of the Society in Philadelphia

Thomas C. McBride, *Chairman* — D. R. Yarnall, *Secretary*
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W. C. Kerr — J. C. Parker
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SOCIETY REPRESENTATIVES

1911

On John Fritz Medal

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JESSE M. SMITH (2)

On National Fire Protection Association

JOHN R. FREEMAN — IRA H. WOOLSON

On Joint Committee on Engineering Education

ALEX. C. HUMPHREYS — F. W. TAYLOR

On Advisory Board National Conservation Commission

GEO. F. SWAIN — JOHN R. FREEMAN
CHAS. T. MAIN

On Council of American Association for the Advancement of Science

ALEX. C. HUMPHREYS — FRED J. MILLER

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INSTITUTION	DATE AUTHORIZED BY COUNCIL	HONORARY CHAIRMAN	PRESIDENT	CORRESPONDING SECRETARY
	1908			
Stevens Inst. of Tech. Hoboken, N. J.	December 4	Alex. C. Humphreys	W. G. H. Brehmer	J. G. Bainbridge
Cornell University, Ithaca, N. Y.	December 4	R. C. Carpenter	A. W. de Revere	D. S. Wegg, Jr.
	1909			
Armour Inst. of Tech. Chicago, Ill.	March 9	G. F. Gebhardt	F. E. Wernick	W. E. Thomas
Leland Stanford Jr. University, Palo Alto, Cal.	March 9	W. F. Durand	J. B. Bubb	H. H. Blee
Polytechnic Institute, Brooklyn, N. Y.	March 9	W. D. Ennis	A. L. Palmer	R. C. Ennis
Purdue University, Lafayette, Ind.	March 9	L. V. Ludy	H. A. Houston	J. W. Barr
University of Kansas, Lawrence, Kan.	March 9	P. F. Walker	C. E. Johnson	C. A. Swiggett
New York Univ., New York	November 9	C. E. Houghton	Harry Anderson	Andrew Hamilton
Univ. of Illinois, Urbana, Ill.	November 9	W. F. M. Goss	B. L. Keown	C. S. Huntington
Penna. State College, State College, Pa.	November 9	J. P. Jackson	W. E. Heibel	G. M. Forker
Columbia University, New York.	November 9	Chas. E. Lucke	F. T. Lacy	J. L. Haynes
Mass. Inst. of Tech., Boston, Mass.	November 9	Gaetano Lanza	Morrill Mackenzie	Foster Russell
Univ. of Cincinnati, Cincinnati, O.	November 9	J. T. Faig	H. B. Cook	C. J. Malone
Univ. of Wisconsin, Madison, Wis.	November 9	C. C. Thomas	A. MacArthur	A. Wegner
Univ. of Missouri, Columbia, Mo.	December 7	H. Wade Hibbard	H. W. Price	Osmer Edgar
Univ. of Nebraska, Lincoln, Neb.	December 7	C. R. Richards	W. J. Wholenberg	W. H. Burleigh
	1910			
Univ. of Maine, Orono, Me.	February 8	Arthur C. Jewett	A. H. Blaisdell	W. B. Emerson
Univ. of Arkansas, Fayetteville, Ark.	April 12	B. N. Wilson	C. B. Boles	W. Q. Williams
Yale University, New Haven, Conn	October 11	L. P. Breckenridge	Clayton DuBosque	W. Roy Manny
Rensselaer Poly. Inst., Troy, N. Y.	December 9	A. M. Greene, Jr.	A. M. Greene, Jr.	Harrison Weaver
	1911			
State Univ. of Ky., Lexington, Ky.	January 10			
Ohio State University, Columbus, O.	January 10			